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UNITED STATES AIR FORCE
SCIENTIFIC ADVISORY BOARD

Report on

UAV Technologies and Combat Operations

(Volume 1: Summary)

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SAB-TR-96-01

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 1996	Final, January 1996 - November 1996

4. TITLE AND SUBTITLE
UAV Technologies and Combat Operations, Volume 1

5. FUNDING NUMBERS

6. AUTHOR(S) P. Worch, J. Borky, R. Gabriel, W. Heiser, T. Swalm, T. Wong

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
AF/SB
Pentagon
Washington, DC 20330-1180

8. PERFORMING ORGANIZATION REPORT NUMBER
SAB-TR-96-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
SAF/AQ
1060 Air Force Pentagon
Washington, DC 20330-1060

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution authorized to US Government agencies and their contractors; administrative or operational use; November 1996. Other requests for this document shall be referred to the Department of the Air Force, AF/SB, Washington, DC 20330-1180

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The Air Force has entered an era in which the unmanned aerial vehicle (UAV) has become not only acceptable, but desirable, for long-endurance reconnaissance missions. Many of the requisite technologies are mature; others need additional development. Moreover, there appears to be greater acceptance of UAVs in the conduct of Air Force mission tasks.

The study group observed the need for an evolutionary approach to introducing the UAV into the Air Force mission, with special consideration given to UAV operation as complementary to manned aircraft. Such an approach will allow technical obstacles to be overcome as well as rules and concepts to be developed for successful integration of UAVs into the civil and military airspace environment and into operational tactics.

The study group concluded that a number of key missions should be pursued as development and demonstration programs by the Air Force. These programs will serve to establish the utility of the UAV and to help develop the operational concepts. An example point design—a Suppression of Enemy Air Defenses (SEAD) UAV with a roadmap for programmatic accomplishment—is provided along with a recommendation that a SEAD demonstration program be pursued. Some special subjects are presented, followed by overall recommendations and concluding remarks.

14. SUBJECT TERMS: Unmanned aerial vehicle, UAV, mission systems, SEAD, modular warhead technology, airspace deconfliction, ACTD

15. NUMBER OF PAGES
94

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	None

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

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Foreword

This volume summarizes the deliberations and conclusions of the 1996 Air Force Scientific Advisory Board (SAB) Summer Study "UAV Technologies and Combat Operations." In this study, we reviewed technology maturity in the context of accepted Air Force mission tasks and projected new mission tasks—both combat and noncombat—that might be enabled by available and forecast technologies. It was an iterative process involving Government and industry experts.

We have tried to provide an objective view of what is often a controversial subject. We believe that unmanned aerial vehicles (UAVs) will be a part of the future Air Force, in all likelihood a significant part. But we also believe that moving too fast to incorporate UAVs into the force structure would be just as dangerous as moving too slowly. Instead, it is important that the Air Force move carefully and methodically, conducting a series of demonstrations designed both to evaluate and mature the technologies and to develop and test the operational concepts.

The Board wishes to thank the many individuals who contributed to the deliberations and the report. In addition to the Board members, many ad hoc members devoted their time. Industry assisted, and Air Force Major Air Command liaison officers were extremely helpful. The Air Force Academy provided technical writing assistance which was most important. We gratefully acknowledge the assistance of the Staff of the UK Defence Research Agency during the summer session. Special recognition goes to the SAB Secretariat staff and the ANSER team for their administrative assistance.

Finally, this report reflects the collective judgment of the SAB and hence is not to be viewed as the official position of the United States Air Force.

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November 1996

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Executive Summary

INTRODUCTION

The Air Force has entered a new era, an era in which the unmanned aerial vehicle (UAV) has become not only acceptable, but desirable, for long-endurance reconnaissance missions. It is timely then, for the Air Force Scientific Advisory Board (SAB) to review technology maturity in the context of accepted Air Force mission tasks and to project new UAV mission tasks—both combat and noncombat—that might be enabled by available and forecast technologies. Thus, the Air Force Chief of Staff directed the 1996 study "UAV Technologies and Combat Operations."

The study report includes a Summary Volume (Volume I) and a Volume that includes the individual Panel reports (Volume II). The Summary Volume deals first with the mission task concepts, then the platform considerations that bound the air vehicle parameters, then the system/sub-system elements (i.e., mission systems and weapons), and finally, the human factors considerations. An example point design—a Suppression of Enemy Air Defenses (SEAD) UAV with a roadmap for programmatic accomplishment—is provided along with a recommendation that a SEAD demonstration program be pursued. Some special subjects are presented, followed by overall recommendations and concluding remarks. The reader is referred to Volume II to more completely understand the approach and deliberations in the specific areas, and to discern a more complete set of conclusions and recommendations. Additionally, some issues for which complete study was beyond the scope of, or time available in this study are also presented in Volume II.

FINDINGS

The study group identified a number of findings relative to the application of UAVs to Air Force roles and missions:

1. *UAVs have significant potential to enhance the ability of the Air Force to project combat power in the air war.*

2. *UAVs have the ability (range, persistence, survivability, and altitude) to provide significant surveillance and observation data economically, compared with current manned aircraft approaches.*

3. *UAVs have the potential to accomplish tasks that are now, for either survivability or other reasons, difficult for manned aircraft including counterair (cratering runways and attacking aircraft shelters), destroying or functionally killing chemical warfare/biological warfare (CW/BW) manufacturing and storage facilities, and suppression of enemy air defenses.*

4. *UAVs can be weaponized in the near-term[1] (perhaps using advanced versions of the Tier vehicles), using an existing weapon and hypervelocity kinetic energy penetrators with a family of warheads.*

5. *Insufficient emphasis has been placed on human systems issues. Particularly deficient are applications of systematic approaches to allocating functions between humans and automation, and the application of human factors principles in system design.*

6. *Most other technologies necessary for platforms, propulsion, avionics, and mission systems are sufficiently mature to provide initial UAV capabilities of the nature described above. Further technology development can significantly enhance these capabilities.*

7. *New warhead technologies—namely intermetallic high temperature self-propagating synthesis reaction incendiary and "flying plate" concepts—can provide the UAV the ability to deliver compact weapons capable of inflicting devastating damage to a large number of fixed and moving targets.*

8. *Little thought has been given to appropriate responses to enemy use of UAVs, particularly those armed with air-to-air missiles.*

In order to fully exploit the potential of UAVs, the Air Force must think of them as new and complete systems with new combinations of advantages and disadvantages, rather than as vehicles with a single outstanding characteristic or as a slight variant of an existing vehicle. Thus, advances must be made across the board, including concepts of operation, platform, weapon, mission systems technologies, and especially, human systems.

OPERATIONAL MISSION AND MISSION TASK CONCEPTS

The study group assessed UAV contributions to Air Force missions and promulgated 22 missions/tasks to which UAVs can contribute. The following nine missions are representative of UAV mission needs and serve as a context in which to address technology opportunities. In no particular order, they are:

- Counter Weapons of Mass Destruction
- Theater Missile Defense—Ballistic Missiles/ Cruise Missiles
- Fixed Target Attack
- Moving Target Attack
- Jamming
- Suppression of Enemy Air Defenses
- Intelligence, Surveillance, and Reconnaissance

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[1] The study group adopted the use of near-term (1996-2005), mid-term (2005-2015), and far-term (2015-2025) as the periods in which initial operational demonstrations could occur.

- Communications/Navigation Support

- Air-to-Air

The study analyzed each of these missions in terms of operational capability and ability to exploit the enabling technologies. Platforms, propulsion, mission systems, and weapons were considered, as were human factors aspects. Challenges were identified and programs were suggested. The Air Force is encouraged to consider these and other missions in more detail and to establish programs in those that, after further analysis, are determined to be appropriate.

The Air Force should also be on a continual lookout for new or non-traditional missions, some of which may complement existing roles (e.g., use of UAVs as the "eyes" for B-52s, thus averting costly B-52 upgrades) and new missions that may leverage technology advances (e.g., seeding and monitoring unattended ground sensors).

DEMONSTRATIONS

The introduction of UAVs into the Air Force operational and organizational structure is considered an evolutionary process, highly dependent on a series of operational demonstrations of which the current Predator, DarkStar, and Global Hawk programs are part. These demonstrations are key to developing technical and operational confidence in UAVs. Specifically, the Air Force has the opportunity for *near-term demonstrations* in the following mission/task areas:

1. *Enhanced ISR missions with electronic support measures (ESM), foliage penetration, and advanced radar sensors, coupled with automatic target cueing or screening, and advanced fusion concepts,*

2. *ESM and jamming payloads for detection, precision location, and neutralization of radio frequency emitting threats,*

3. *Fixed and moving target attack using UAVs to detect and locate targets based on image-coordinate transformation, cueing, and advanced lightweight weapons,*

4. *Communications and navigation support, based on the Defense Advanced Research Projects Agency (DARPA) UAV Communications Node concept, but adding Global Positioning System (GPS) augmentation pseudolites for precision guidance under GPS jamming,*

5. *Suppression of enemy air defenses.*

RECOMMENDATIONS

The study Panel made numerous detailed recommendations which are found in Volume II. The major recommendations are outlined below, with more detail on each provided in Chapter 11 of this Volume. The Air Force should:

1. *Take the lead role in programs to exploit the near-term UAVs (Predator, DarkStar, and Global Hawk) in Air Force, Joint and National roles.*

2. *Pursue the SEAD mission as an early application of UAVs in an attack role.*

3. *Initiate a program, perhaps with DARPA, that leads to the development and deployment of advanced penetrating combat UAVs in the mid- to far-term.*

4. *Increase emphasis on effective techniques for flight management and employment of UAVs.*

5. *Establish UAV experimental capabilities to address crew-vehicle flight management concepts and increase emphasis on human system related topics in development programs.*

6. *Expand work in engines, air vehicle structures, and flight management technologies.*

7. *Supplement avionics and mission systems technology base programs in mission system automation, miniaturization, and sensor aperture areas critical to UAV operations.*

8. *Initiate a modular weapons and warhead program specifically oriented to the mission tasks most suited to UAVs.*

9. *Initiate a broad program to address opportunities for dramatically reducing operations and support costs for UAVs.*

10. *Promote command, control, communications, and intelligence (C^3I) architectures that consider UAVs in the context of the overall Joint Forces structure.*

11. *Develop systems, concepts, and processes for UAV airspace management and deconfliction.*

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List of Acronyms

Acronym	Definition
A/D	Analog/Digital
AAM	Air to Air Missile
ABCCC	Airborne Command and Control Center
ABL	Airborne Laser
ACO	Airspace Coordination Order
ACTD	Advanced Concept Technology Demonstration
AEW	Anti-Electronic Warfare
AJ/LPI	Anti-Jam/Low Probability of Intercept
ALCM	Air Launched Cruise Missile
AMRAAM	Advanced Medium Range Air to Air Missile
ATBM	Anti-TBM
ATC	Automatic Target Cueing
ATR	Automatic Target Recognition
AWACS	Airborne Warning and Control System
BPI	Boost Phase Intercept
C2 or C^2	Command and Control
C^3I	Command, Control, Communications, Intelligence
CDL	Common Data Link
CEB	Combined Effects Bomblet
CEP	Circular Error Probable
CFE	Conventional Forces Europe
CL	China Lake
CMD	Cruise Missile Defense
CONUS	Continental United States
COTS	Commercial Off the Shelf
CRC	Command Reporting Center
CW/BW	Chemical Warfare/Biological Warfare
CWMD	Counter Weapons of Mass Destruction
DARO	Defense Airborne Reconnaissance Office
DARPA	Defense Advanced Research Projects Agency
DGPS	Differential GPS
DIS	Distributed Interactive Simulation
DoD	Department of Defense
DTM	Digital Terrain Map
ECCM	Electronic Counter Counter Measures
ECM	Electronic Counter Measures
EMD	Engineering and Manufacturing Development
EO	Electro-Optical
ESM	Electronic Support Measures
EW	Electronic Warfare
FAA	Federal Aviation Administration
FLIR	Forward Looking Infrared

FOPEN	Foliage Penetrating
fps	feet per second
ft	feet
GPS	Global Positioning System
HAE	High Altitude Endurance (P-Penetrating, S-Standoff, C-Combat)
HOBO	Homing Bomb
HOTAS	Hands on Throttle and Stick
HPM	High Power Microwave
hr	hour
HSI	Human Systems Integration
ICAO	International Civil Aviation Organization
IFF	Identification Friend or Foe
IHPTET	Integrated High Performance Turbine Engine Technology
in.	inch
INF	Intermediate Nuclear Forces
INS	Inertial Navigation System
IOC	Initial Operational Capability
IR	Infrared
IRCM	Infrared CounterMeasure
IRST	Infrared Search and Track
ISR	Intelligence, Surveillance, Reconnaissance
JDAM	Joint Direct Attack Munition
JSOW	Joint Standoff Weapon
kg	kilogram
KKV	Kinetic Kill Vehicle
L/D	Lift to Drag
LADAR	Laser Distancing and Ranging
lb	pound
LIDAR	Light Distancing and Ranging
LO	Low Observable
LOCAAS	Low Cost Autonomous Attack System
LOS	Line of Sight
MCE	Mission Control Element
MDS	Mission Design Series
MEMS	Micro ElectroMechanical Systems
MMW	Millimeter Wave
MPT	Manpower, Personnel, and Training
MTI	Moving Target Indicator
NBC	Nuclear, Biological, and Chemical
NIIRS	National Imagery Interpretation Rating Scale
nm	nautical mile
NSWC	Naval Surface Warfare Center
O&M	Operations and Maintenance
OJT	On the Job Training
OOTW	Operations Other Than War
P_k	Probability of Kill
P_{ssk}	Probability of Single Shot Kill
psf	pounds per square foot

psi	pounds per square inch
RCS	Radar Cross Section
RF	Radio Frequency
RFCM	Radio Frequency Countermeasure
RTIC	Real Time Information to the Cockpit
s	second
SAB	Scientific Advisory Board
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SEAD	Suppression of Enemy Air Defenses
SFC	Specific Fuel Consumption (see also TSFC)
SIGINT	Signal Intelligence
SIOP	Single Integrated Operations Plan
START	Strategic Arms Reduction Treaty
TBM	Theater Ballistic Missile
TCAS	Terrain Collision Avoidance System
TDOA	Time Difference of Arrival
TMD	Theater Missile Defense
TOGW	Takeoff Gross Weight
TSFC	Thrust Specific Fuel Consumption (see also SFC)
TUAV	Tactical UAV
UK	United Kingdom
US	United States
UAV	Unmanned Aerial Vehicle
UCN	UAV Communications Node
UGS	Unattended Ground Sensor
UHF	Ultra-High Frequency
USAF	United States Air Force
UTA	Unmanned Tactical Aircraft
VHF	Very High Frequency
VLO	Very Low Observable
WMD	Weapon of Mass Destruction

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Chapter 1

Background

Unmanned aerial vehicles are not new to warfare or to the Air Force. The Firebee, later designated the BQM-34, became the standard jet target for scores of uses by the Air Force, Navy, and Canadian forces.[2] Over 6,500 of the versatile jets have been built, which became the basis for the evolution of UAVs.

During the 1950s, the US relied on manned reconnaissance flights near and behind the Iron Curtain to gather valuable intelligence information about the Soviet Union. The BQM-34 was demonstrated using existing photo reconnaissance cameras. Later, a BQM-34 with larger wings designed to fly at high altitude, was developed as the first UAV designed specifically intended for the reconnaissance mission.[3] This vehicle, the Ryan 147 B (AQM-34Q), was used operationally for intelligence collection against Cuba, and later in Vietnam.

Several demonstration programs used the unmanned aircraft in flak suppression, chaff dispensing, target designation, and weapons delivery roles, but these missions were never performed operationally. There were tests of unmanned drone aircraft in air-to-air combat roles. The AQM-34 demonstrated dropping 500 lb bombs, dropping the Stubby-Homing Bomb (HOBO), and launching the electro-optically guided Maverick missile. Although these demonstrations were successful, termination of the Vietnam conflict ended the expanded roles of UAVs. The end of the conflict was also marked by a massive drawdown of US military forces, including the elimination of Air Force UAV organizations in 1976.

After the Vietnam drawdown, the Air Force appeared to lose all interest in UAVs, with little activity until the initiation of the Tier 2 (Predator), Tier 2+ (Global Hawk), and Tier 3- (DarkStar) reconnaissance-surveillance programs. Suddenly, interest increased with the promise of a new generation of vehicles boasting automated flight, long endurance, and “modest” cost relative to manned reconnaissance aircraft. Table 1-1 provides data on the Air Force current/developmental UAVs.

All has not been successful in the UAV world. Many air vehicle crashes have marred its history, reducing confidence and programs. Many aircraft crashed on take-off and landing, perhaps due to the remoting of the pilot from the aircraft without providing sufficient situation awareness information and “seat-of-the-pants” feeling to perform the piloting operation. Other unmanned aerial vehicles were successful in flight, but achieved disfavor for reasons of program cost growth or system performance limitations. Yet other UAV programs were driven to their death by requirements growth or simply poor timing. The Aquila program is a prime example of the former.[4] Further detail on the history of UAVs is provided in Volume II, Chapter 1, Appendix C.

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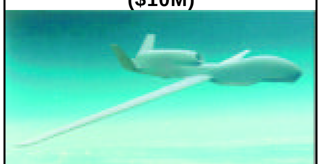
[2] William Wagner: *Lightning Bugs*, Fallbrook, CA: Armed Forces Journal International, 1982.

[3] US Army Aviation Center: *Unmanned Aerial Vehicle Study*, Ft Rucker, AL, 1993.

[4] Brig Gen David R. Gust: *The Last Three Years of Aquila and How the Army Failed to Field New Technology*.

Table 1-1. *Air Force Unmanned Aerial Vehicles*

Air Vehicle Data		***Payload***	***Status***
Tier 2 Predator **($3.2M)** 	Gross Wt (lb) - 2,000 Altitude (ft) - 25,000 Endurance (hr) - 50+ Payload (lb) - 450 Wingspan (ft) - 49 Airspeed (kts) - 80	SAR - 3 m, 0.3 m EO/IR - NIIRS 6.5 Ku, UHF SATCOM CDL, UHF LOS Comm	Operational
Tier 2+ Global Hawk **($10M)** 	Gross Wt (lb) - 24,000 Altitude (ft) - 65,000 Endurance (hr) - 42 Payload (lb) - 2,000 Wingspan (ft) - 116 Airspeed (kts) - 300	SAR - 3 m, 0.3 m to 200 km EO/IR - NIIRS 6.5/5/5 Ku, UHF SATCOM CDL, UHF LOS Comm	In Build
Tier 3- DarkStar **($10M)** 	Gross Wt (lb) - 8,600 Altitude (ft) - 45,000 Endurance (hr) - >8 Payload (lb) - 1,000 Wingspan (ft) - 69 Airspeed (kts) - 350	SAR - 3 m, 0.3 m EO/IR - NIIRS 5 Ku, UHF SATCOM CDL, UHF LOS Comm	In Test (#1 Crashed)

Chapter 2

General Discussion

The study group adopted the term "unmanned aerial vehicle" (UAV) to describe the realm of unmanned aircraft. UAVs can be air vehicles specifically designed to operate without an onboard operator (e.g., Global Hawk) or aircraft intended to be manned that have been converted to unmanned operation (e.g., unmanned F-16). They can act in surveillance/reconnaissance roles, attack roles, or other support (jamming, for example) mission tasks. For the purposes of this study, cruise missiles and drones were not considered as UAVs, although UAVs could perform their missions.

The time for UAV acceptance appears to be here for a number of reasons. First, the declining force structure, people, and equipment necessitates innovative thinking about solutions that more cost-effectively accomplish Air Force missions. Secondly, technologies have emerged and matured as very significant enablers for unmanned missions (GPS for example). Thirdly, operations and support budgets are limited and there are opportunities for UAVs to provide lower operating cost and increased sortie rates. Fourth, among other attributes, the extreme endurance and potential for high flight altitude of UAVs could bring a new dimension to Air Force operations. And finally, the Air Force senior leadership is actively interested in the unmanned aerial vehicle. It remains up to the development and operational communities to cooperate in demonstration efforts that establish the viability of the UAV.

The purpose of this study was to assess system concepts as well as technologies in platforms, mission systems, weapons, and human factors as they might pertain to the accomplishment of relevant Air Force operational tasks. These assessments should help the Air Force better invest in UAV technologies and systems for the future.

The study recognizes that UAVs are not a panacea; some missions can benefit by the use of UAVs but others are better left to manned aircraft. It is important that the Air Force make the determination as to the manned versus unmanned mix. The study group, on the other hand, recognizes the important technical and operational attributes of UAVs and the functional impacts of their use as a complement to manned aircraft (see Table 2-1).

The decision to field UAVs and whether to augment or replace manned aircraft must be made after careful consideration of many factors:

- The scenarios to be encountered
- The missions and tasks
- The alternatives
- The relative risks
- The relative costs of the tasks
- The maturity of the technologies

The determination of the manned-unmanned force mix was beyond the scope of this study. In the opinion of the study group, the force mix issue can be addressed only after demonstrations (Advanced Concept Technology Demonstrations [ACTDs] for example) of operational capability and utility, and the associated formulation of operational concepts. It should be stressed that the force mix decision process is especially complex for unmanned vehicles because the introduction of such radically new weapon systems carries a great deal of uncertainty about capability, and because the methodology and models to address such complexities are not yet in place.

Table 2-1. *Major Attributes of UAVs*

Attribute	***Functional Impacts***
Endurance/Presence	Persistent Surveillance Continuous Deterrence Reduced Aircraft-per-Orbit Quantities Required Reduced Crew Fatigue Broad, Distributed Communications Relay Self-Deployable From CONUS; Can Operate From CONUS Reduced Cost of Coverage
Unmanned	Perform High Attrition Combat Tasks Carry Weapons (With Fratricidal Possibilities) Operate in Contaminated Environments Operate in Provocative Role, Drawing Fire Potentially Simpler: Reduced Cost Reduced Crew Fatigue Problem Less Thorough Safety Testing Required Potential Kamikaze Employment Reduced Cost of Coverage Less Reasoning Power Than Manned Aircraft Greater Need For Command & Control Tether Crew-Saves (Aircraft & Mission) More Difficult, Less Likely
Automated	Simpler, Less Costly Training No Crew Safety Testing Control Interface Simpler Than Remotely Piloted Aircraft Less Stressing to Crews Reduced Cost of Coverage Reduced Physical Requirements for Operators Crew-Saves (Aircraft & Mission) More Difficult, Less Likely
Distributed & Proliferated	Quick Response Within Zone of Coverage Behind-the-Lines Operation Combined Attack (Multiple Weapons) Broad Area Coverage With Multiple Sensors Persistent Surveillance Reduced System Vulnerability
High Altitude Operation	Survivable Performance Enhancements Broad Area Coverage Reduced Cost of Coverage Better Viewing Angle For Enhanced Target Doppler, RCS Advantageous Geometry For TBM Intercept
Low Altitude Operation	Loss Affordable Operate at Short Range (Smaller Weapons, Jammers, Radars)

The concept of weaponizing UAVs may seem radical or risky but closer examination of the evidence suggests otherwise. Other nations are currently weaponizing their own UAVs and the US has taken similar steps with drones and cruise missiles. The Israelis, for example, have been particularly successful in the development and operation of UAVs. Furthermore, it appears that UAV platform, sensor, and weapons technologies have matured sufficiently to permit low risk, rapid, and low-cost development and application of weaponized UAVs. The operational risk, on the other hand, is considerable, for the integration of UAVs with manned aircraft into the operational architecture is a major step in the near-term.

Though the individual technologies are relatively mature in most cases, the development of UAVs is certainly lagging. In fact, the key technologies that could and should be applied to the development of unmanned aerial vehicles are depicted in three timeframes in Table 2-2.

Table 2-2. *Technologies for Advanced UAVs*

Technology	***Past***	***Present***	***Future***
Affordability	Marginal	Design to Cost Implemented	Low Life Cycle Cost Realized
Data Links	Analog/Low Bandwidth	Digital, High Cost for Bandwidth	Standardized for USAF Architecture, Modular, Affordable
Engines	Whatever Available	Off-the-Shelf Commercial	Designed for UAVs, More Fuel Efficient
Human Systems	Automate What Was Technically Feasible; Human Filled the Gaps	Inconsistent Function Allocation; Minimum Attention to Human Factors	Simulation-based Design for Systems Relevant to Human
Low Observables	None	Current Technology: Some Penalties Perceived Costly	Lower Penalties, Lower Signatures, Lower Cost
Mission Planning	Little Automation	Some Automation, Slow, Inflexible	Automated, Flexible, Fast, Utilizing Parallel Computers
Onboard Processors	Limited Capability	Good Capability at Reasonable Cost	Excellent Performance/Low Cost
Producibility	Not Emphasized	Major Advances, Low Cost Tools for Composites	Designed for Low Rate, Low Cost Production
Sensors	Heavy, Bulky, Marginal Reliability	Major Improvements	Modular, Lightweight, UAV-Tailored
System Design Integration	Modified Manned Aircraft Techniques	Design Automation System Simulation	Integrated Design/ Simulation/ Manufacturing Automation
System Reliability	Marginal	Better, but not Acceptable	Robust Systems, Very Low Failure Rate
Training	Reliance on Prior Experience and OJT	Delegated to Contractors; Military Training Evolving	Crew Selected and Trained Using Modern Methods
Vehicle Management Systems	Off-the-Shelf, No Integration, No Automation	Some Integration, Rudimentary Automation	Optimized for UAVs: Performance, Weight, Cost, Automation
Vehicle Structure	Manned A/C Metal Approach, Large Parts Counts	Composites Not Fully Exploited, Reduced Part Count	Tailored Composite Structure, Very Low Part Count, High Fuel Fraction
Weapons	None	Little Consideration	Small, Modular, Integrated System Design

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Chapter 3

Operational Mission and Task Concepts

The study group reviewed current Air Force roles and missions and determined how UAVs might contribute to the significant capabilities that already exist in manned systems. Each Air Force mission (AFM 1-1) was reviewed for its applicability to UAV development. Further, the study group considered UAV contributions to "core competencies" and "Air Force Capabilities" promulgated by the Secretary of the Air Force and the Chief of Staff.

A number of driving factors were considered along with the UAV's contribution to mission success. These included platform characteristics, degree of autonomy in vehicle/flight management, reliability and maintainability, airspace deconfliction procedures, abort procedures, deployment considerations, strike (lethal) versus support, remote versus forward basing, information and mission systems processing survivability, weapons integration and employment, and human factors (C^2, training, selection, etc.).

From the expanded mission list shown below, the first nine missions were selected as both being critical to Air Force needs and being representative of the 22 missions for purposes of technology considerations. Detailed descriptions of the mission concepts are included in the Panel reports in Volume II.

- Counter Weapons of Mass Destruction
- Theater Missile Defense—Ballistic Missiles/Cruise Missiles
- Fixed Target Attack
- Moving Target Attack
- Jamming
- Suppression of Enemy Air Defenses
- Intelligence, Surveillance and Reconnaissance (ISR)
- Communications/Navigation Support
- Air-to-Air
- Base Defense
- Strategic Attack
- Space Control
- Special Operations
- Area Denial
- Decontamination & Defoliant Dispensing
- Combat Search and Rescue
- Trans/Post SIOP Missions
- Refueling Tanker
- Cargo Transport
- GPS Augmentation
- Information Warfare
- Humanitarian Assistance

The study group reviewed the DARPA Unmanned Tactical Aircraft (UTA) initiative and some of the industry responses to "uninhabited" vehicle solutions, the Army's recent Tactical UAV (TUAV) program selection (Alliant Techsystems), and the QF-106 and QF-4 drone programs. The group concluded that there are opportunities for proof-of-concept work in the near-term with some of these programs. Especially attractive are demonstrations of multiple aircraft connectivity scenarios, communications jamming, and lethal (weapons delivery) application of UAVs. Clearly, some of these UAV concepts will best complement manned systems and should be considered supportive platforms, whereas others can evolve to autonomously accomplish pre-planned and dynamically tasked missions autonomously.

3.1 KEY MISSIONS AND TASKS

The first nine UAV mission concepts in the list above have great practical and technological potential for strengthening the Air Force capabilities by complementing the existing force structure. These missions are selected because:

- they address Air Force needs and requirements as articulated by senior leadership,
- they are operationally useful for Joint needs,
- the technology base exists to support successful mission accomplishment,
- they are representative of the design, development and enabling technology needs for platforms, mission systems, weapons, and human systems for all 22 missions.

The remainder of this section provides a brief description of the missions/tasks as a preface to the system discussions to follow.

3.1.1 Counter Weapons of Mass Destruction (CWMD)

High on any critical task list for the Air Force is the capability to locate and destroy weapons of mass destruction (WMD). Operational concepts include the use of UAVs in this force application role—a strategic attack mission—to assist in the determination of possession, manufacture, storage, and movement of nuclear, biological, and chemical (NBC) material and devices by adversaries. UAVs would complement other forces in performing this difficult and complex task, taking advantage of long-term presence in close proximity to the targets.

For the far-term, the UAV would destroy WMD without dispersing the hazardous materials. The strike would be carried out by a dual-equipped UAV (multi-spectral sensors and weapons) or the surveillance UAV flying in conjunction with weapons-carrying UAVs. If a strike decision is made, precision guided penetrating weapons or specialized kill mechanisms that prevent contamination would be utilized. Battle damage assessment would be necessary to determine status and future actions.

3.1.2 Theater/Cruise Missile Defense (TMD/CMD)

The role of Aerospace Control is enhanced by UAVs participating in the mission of counterair, defending against theater and cruise missiles. In the very near-term, long-endurance UAVs that have surveillance, reconnaissance, and attack capability could augment manned systems in the TMD Theater Ballistic Missile (TBM) mission. These long-endurance UAVs would provide Joint Force Commanders with a flexible asset able to support the TMD TBM mission with long loiter time, multi-spectral near-real-time wide area surveillance, complete C^3 linkage, survivable deep penetration into enemy territory, and coverage in high numbers at altitudes that provide advantageous geometries for intercept of the hostile missile. Weaponized UAVs may also supplement existing and next-generation attack assets. In the mid- to long-term, very low observable (VLO), very high altitude long-endurance UAVs could further augment the TMD TBM mission and cruise missile defense resources.

3.1.3 Fixed Target Attack

Combat UAVs would be employed to attack high value fixed targets in the force application role, supporting operations in the missions of strategic attack, interdiction, and close air support. Given the location, type of target, and desired weapons effects from ISR and C^2 nodes, a target attack mission would determine attack axes and tactics to optimize target acquisition, weapons effects, collateral damage, and terminal guidance (GPS aided, electro-optical [EO], infrared [IR], or millimeter wave [MMW]).

3.1.4 Moving Target Attack

Sensor-carrying high-altitude endurance (HAE) UAVs complement other ISR assets. UAVs would operate at long range for long periods, providing ISR of enemy territory. The ISR assets would be linked in a flexibly cross-linked C^2 architecture, cueing loitering weapons platforms to attack identified targets. The weapons platform would be a manned strike fighter in the near-term and an attack UAV in the future. Typical missions covered by moving target attack are interdiction, strategic attack, and close air support.

3.1.5 Jamming

The UAV could operate as a high altitude, long endurance/low observable electronic support measures/electronic countermeasures (ESM/ECM) platform supporting multiple strike/bomber attack operations in standoff or close in orbits. Long endurance would permit the UAV to support multiple strike force packages or single aircraft strikes at varying geographic locations. The vehicle would have the ability for pre-planned orbit navigation or ground and airborne dynamic re-tasking in support of revised targeting. A second mid-term jamming concept would be a high speed penetrating UAV that preceded or accompanied strike vehicles, providing jamming against fire control tracking radars found around protected enemy targets. An adjunct to the jamming UAV might be a decoy UAV which replicated the signature (radar cross section [RCS], infrared signature, and radio frequency [RF] transmitters) of a fighter aircraft.

3.1.6 Suppression Of Enemy Air Defenses

UAVs could detect enemy air defense systems and pass detection and precision location data to elements of the SEAD network that would deploy attack weapon systems and bomb damage assessment systems. In the near-term, UAVs would augment the “total” force by collecting emitter data on enemy air defense systems; manned aircraft would deliver weapons. In the near- to mid-term, however, a SEAD attack vehicle is feasible. The persistence of UAVs can serve to curtail or disrupt enemy defense system effectiveness.

3.1.7 Intelligence/Surveillance/Reconnaissance

UAVs bring to ISR missions the helpful capabilities of flying close to the target and enjoying flexible positioning, long dwell, and loitering. If further aided by very low observability to facilitate overflying of enemy territory, UAVs have the potential for significant contribution to the Air Force goal of providing “the ability to supply responsive and sustained intelligence data from anywhere within enemy territory, day or night, regardless of weather, as the needs of the warfighter dictate.” This is equally applicable when the “enemy territory” is “crisis territory” and the situations are Operations Other Than War (OOTW).

3.1.8 UAV Communications Node (UCN)

The UAV-based multi-band, multi-mode communications relay and switching/gateway node contribute to the force enhancement role by supporting early entry and force buildup, linkage between remoted battlestaffs and warfighting line-of-sight communications, and backup and surge support for fast moving fighting forces. Currently, most theater C^2 and strike assets have only limited capability for servicing unattended ground sensors (UGS). The value of such support is manifest in most offensive operations phases when a tactical communications network is limited in keeping pace with the fast moving forces, not only in physical speed but in power, frequency, bandwidth, available channels, and avoidance of interference. Forces separated in widely dispersed enclaves beyond line-of-sight communications would be assisted.

3.1.9 Air-To-Air Combat (Offensive/Defensive)

The offensive and defensive threat associated with air-to-air combat in the future will consist of enemy manned aircraft as well as air-, ground- and sea-launched cruise missiles and ballistic missiles. It will be characterized by the necessity for quick and absolute dominance. UAVs would participate in air-to-air combat by air-to-air ambush and by high speed, high "g" interception. Each would be employed in a defensive or offensive role, depending on the target and scenario. As air-to-air UAVs enter the inventory, manned aircraft can be assigned to other missions.

3.2 OPERATIONAL MISSION/TASK SUMMARY

Nine UAV mission concepts have high practical and technological potential for strengthening the current Air Force capability by complementing the existing force structure. UAVs could, in the very near-term, gather target location data though manned aircraft would employ the weapons. Employment of weapons from UAVs is not a near-term technical issue but is limited by operational policy and procedural considerations. In the mid-term, some UAVs would gather target location data and other UAVs, in concert with manned aircraft, would attack the targets. In the far-term, UAVs would both gather target location data and attack the targets in autonomous areas of operation (kill boxes). Although air refueling has not shown significant benefits to any of the missions described in the study, it should be included in any comprehensive consideration of UAVs. Categories of UAV platforms as well as mission systems and weapons were established for each mission as shown in Table 3-1.

Table 3-1. *Mission Summary*

Mission	***Platform***	***Mission Systems***	***Weapons***
CWMD	P-HAE (Find/Attack) C-MAE (Find/Attack)	NBC Sensors, Target Geolocation, UGS Relay	Penetrator Missile with Thermitic Warhead or Employing Sealant Foam
TMD/CMD	S-HAE (Find/Attack) P-HAE (Find) C-MAE (Attack)	SAR/MTI Radar, Air-to-Air Tracking Radar, EO/IR Imaging Fire Control	Hypervelocity Missile with IR Seeker and Kinetic Kill Vehicle w/ Divert Thrusters
Fixed Target	S-HAE (Find) P-HAE (Find/Attack) C-MAE (Attack)	SAR, EO/IR Imaging, Target Geolocation, Fire Control	Range of Choices Depending on Target Hardness; New Lethal and Small Warheads (Flying Plate, HPM, Thermite) for Future
Moving Target	S-HAE (Find) P-HAE(Find/Attack) C-MAE (Attack)	SAR/MTI Radar, Target Geolocation, Fire Control	Wide Area Submunitions or Homing Missiles such as TOW, Hellfire, Maverick in Near-Term; 3.5 in. Modular Missile for Future
Jamming	S-HAE	ESM Sensors, Escort/Area Jammer, Comm Jammer	N/A
SEAD	S-HAE (Find) P-HAE (Find) C-MAE (Attack)	ESM, Emitter Geolocation, Escort/Area Jammer, Comm Jammer	Weapon Dispenser on UAV, ARM, or Dispensing Submunitions in Near-Term, HPM Warhead or Submunitions on Hypervelocity Missile in Future
ISR	S-HAE (Find) P-HAE (Find)	SAR/MTI Radar, Air-to-Air Tracking Radar, FOPEN Radar, ESM, Emitter Location, Target Geolocation	N/A
UCN	S-HAE P-HAE	Comm Gateway/Relay, GPS Augmentation	N/A
Air-to-Air	S-HAE (Find/Attack) P-HAE (Find) C-MAE (Find/Attack)	Air-to-Air Tracking Radar, Fire Control	AIM-120 and AIM-9 In Near-Term, Hypervelocity Missile in Future
(ALL)		Command/Data Links, Nav/Positioning, Self-Protection, Onboard Processing, Sensor ECCM	GPS Weapon Initialization, Weapon Launch System

Legend: P-HAE Penetrating High Altitude Endurance UAV

S-HAE	Standoff High Altitude Endurance UAV
C-MAE	Combat Medium Altitude Endurance UAV

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Chapter 4

Platform Considerations

4.1 CANDIDATE UAV SELECTION FOR NEAR-TERM EMPHASIS

To progress toward a definition of the overall platform technology requirements for UAVs, the study grouped technology needs as is customary. It began with the 22 original UAV missions/tasks, assessed their attributes, and then pared down the candidate air vehicles to a limited number that represents the spectrum of platform requirements. The process is described below; the results are also presented in Table 3-1.

4.1.1 Vehicle-Defining Attributes

When considering a minimum set of representative vehicles as a basis for advocating an introductory pathway and deriving leverage technologies, several factors should be taken into account as listed in Table 4-1.

Table 4-1. *Vehicle-Defining Attributes*

Attributes
• **Mission Performance** - Altitude (sensor line-of-sight, survivability) - Payload Fraction (endurance per gross weight) - Speed (search rate, response time, survivability) - Endurance (on-station fraction, basing flexibility) • **Logistics and Operating Economics** - Size (acquisition, operating, and basing cost) - Reliability (accident-related operating cost) - Storability (training, operating, and basing cost) - Maintainability • **Payload Accommodation Flexibility** - Bay Volume - Aperture Real Estate - Weapons Integration and Launch - Auxiliary Power - Cooling • **Survivability** - Observables (alert and track denial) - Vulnerability - Maneuverability

Five of these factors bear special mention:

> *Altitude* - Sensor and communication link line-of-sight reach is the primary driver, with survivability secondary. An altitude of 65,000 ft offers over 300 nm to the radio horizon

(disregarding multipath difficulties) and over 100 nm for 5 degree grazing angle SAR or MTI. Flying at altitudes above 5,000 ft defeats most radar directed guns and above 15,000 ft defeats most shoulder launched homing weapons. Altitudes greater than 60,000 ft defeat the bulk of older SAMs and above 70,000 ft prevent fighters from reaching co-altitude. However, even at 70,000 ft air-to-air missiles can be launched to higher altitudes.

Endurance - The value of endurance is primarily in the economics of fleet size necessary to maintain one vehicle continually on station and secondarily in the flexibility of basing far from the theater of action. On-station to transit-time ratios of less than 1:1 require more than two vehicles (plus backup) to maintain one on station. An operating radius of 6,000 nm to station allows CONUS basing to cover most of the world. A nominal 3,000 nm radius allows nearly world coverage from four politically secure bases (Roosevelt Roads, Mildenhall, Diego Garcia, and Guam). A 1,000 nm radius is sufficient for most in-theater sanctuary operations.

Reliability - The accidental loss rate has been the single biggest contributor to the historic failure of UAVs to find their place in the force mix. Flight management systems (including onboard flight control, communication links, and ground station support) are the primary contributors to this shortfall. A mean-time-between-accidental-loss of greater than 20,000 hr is necessary to keep the imputed loss-related cost-per-flight hour below $500 for a $10M surveillance vehicle that might have a total operating cost of $2,000/flight hour.

Storability - For those unmanned vehicles with little peacetime application (e.g., weapon carriers and countermeasure vehicles), large savings in operations and maintenance (O&M) can be achieved by merely warehousing a large fraction of the fleet and relying on simulators and a small active fleet fraction for training. This requires a "wooden round" vehicle for fast surge response.

Aperture Accommodation - Antennas and optics apertures can interfere with signature reduction or, in the case of AEW aircraft, flight-efficient configuration. For ground imaging systems, a 3 ft x1 ft SAR/MTI antenna, 4 in. optics and 3 ft diameter SATCOM antenna is the minimum. For VHF/UHF radar, at least a 40 ft x4 ft antenna is necessary against LO/VLO cruise missiles and aircraft. For anti-TBM, 4 in. optics is considered minimal.

4.1.2 Near-Term Candidates

Of the original 22 vehicle classes listed in Chapter 3, three vehicle types can provide the size, configuration, observables, loiter altitude, endurance, payload, and payload power to economically support most of the priority mission tasks and appropriate sensor/weapon/communication suites *in the near-term.* The study group strived to limit the number of dissimilar vehicles recommended for development and arrived at the three candidate vehicle types described in Tables 4-2 and 4-3.

Early forms of penetrating and standoff HAE vehicles have already been initiated as Predator (Tier 2), Global Hawk (Tier 2+), and DarkStar (Tier 3-) ACTDs. These ACTD programs should be completed to fully explore the potential mission options, degrees of autonomy, ground support, communication architectures, and acquisition strategies before deciding on the particulars of a formal, much improved design follow-on.

Table 4-2. Notional Characteristics of Candidate UAVs

Vehicle Type	*Observables*	*Speed*	*Altitude*	*Payload Power*	*Endurance*	*Aperture*
Penetrating HAE	VLO	M 0.6	>70,000 ft	2,000 lb 20 kW	64 hr	3 ft x 1 ft +3 ft dia +4 in. optics
Standoff HAE	Conventional	M 0.6	>70,000 ft	2,000 lb 100 kW	64 hr	40 ft x4 ft +3 ft dia +4 in. optics
Combat MAE	LO	M 0.6	>40,000 ft	2,000 lb 10 kW	21 hr	1 ft dia

Table 4-3. Applicability of Candidate UAVs

Vehicle Type	*Functions Served*	*Missions Served*
Penetrating HAE	Surveillance, Reconnaissance, Interceptor Carrier	ISR, CWMD, Fixed, Mobile, SEAD, ATBM
Standoff HAE	Surveillance, Communications, Standoff Jammer, Interceptor Carrier	ISR, Fixed, Mobile, SEAD, Air-to-Air
Combat MAE	Strike Weapon Carrier	CWMD, Fixed, Mobile, SEAD, Air-to-Air

The Combat MAE concept is sufficiently embryonic as to need a "crawl-before-walk" requirements definition phase, particularly with respect to vehicle characteristics, which are highly dependent on anticipated, but undemonstrated, weapon size reduction. The Combat MAE UAV also encompasses an extremely broad spectrum of possibilities, ranging from weapon-bearing "trucks" that emphasize loiter to maneuverable aircraft that emphasize penetration. Automating existing combat aircraft could provide near-term surrogates to explore the vehicle/flight management, performance, tactics, and communication architecture issues before taking on a more expensive clean-slate combat vehicle demonstration program, ACTD or otherwise.

In the mid- to long-term, it will become possible and desirable to develop true combat UAVs that are the counterparts of present-day fighter planes. They will exploit various degrees of speed, stealth, maneuverability, and survivability and carry the necessary mission systems and weapons to make possible military actions deep within the heavily defended portions of enemy territory. These combat UAVs will be especially productive for CWMD missions and against extremely important fixed and moving targets and will minimize the exposure of Air Force pilots to danger. Much of their technology will have been developed for the endurance UAVs that precede them, although they will require special emphasis on mission systems and human systems over and above that otherwise available.

4.2 PLATFORM TECHNOLOGY CHALLENGES

This section sets forth, in what is judged to be priority order, the critical enabling technologies that must be developed. These conclusions are based upon several quantitative preliminary design analyses, such as for the SEAD mission vehicle described in Chapter 8, as well as the information gathered from various sources during the study. Since the development of adaptive-autonomous control systems technology;

new propulsion systems; and advanced, lightweight, low-cost UAV structural design approaches are critical to future UAV designs.

4.2.1 Adaptive, Autonomous Control System Technology

Perhaps the most critical issue pacing the evolution of UAVs is that of manual (human) versus automatic (machine/computer) control of the wide range of functions to be executed during a mission. Human controllers have limitations (such as the number of parameters that can be controlled simultaneously and the speed at which humans can respond to sensed changes), but they also have unique abilities not yet replicated in automatic controllers. The human can *learn* to perform control functions and can thus *adapt* to unexpected inputs and demands. Humans can also *reason* effectively under conditions of uncertainty and perform higher order integration tasks.

One difficulty that a designer faces for both manned and unmanned systems is how to integrate human controllers with the vehicle platform systems. That *difficulty remains* and *may be exacerbated* in the complex "system-of-systems" in which UAVs are expected to operate. This topic is treated further in Chapter 7 of this Volume and in Chapter 6 of Volume II.

In a mission-oriented "system-of-systems," a first consideration is the allocation of control functions to all systems within the overall "system-of-systems." Single aircrew vehicles, multiple crew vehicles, unmanned vehicles, manned and unmanned ground stations, manned and unmanned satellites, and all other elements must have their functions determined (through simulations, models, analyses, and tests) and adjusted as operational concepts evolve. The goal is to achieve best performance at affordable cost.

4.2.2 Propulsion System Technology Development Requirements

The projected UAV missions call for a spectrum of requirements for propulsion system technology and a great difference in the level of necessary technology compared with existing engines. For the Combat MAE UAV, current engines appear to be adequate, and improved versions are being made available via the Integrated High Performance Turbine Engine Technology (IHPTET) program. For the HAE (higher altitude and longer endurance than Global Hawk) UAV however, there is a substantial gap between requirements and the existing technology.

The basic criterion for endurance aircraft is fuel usage; engine thrust-to-weight is less important. Issues to be addressed therefore, relate to the directions in propulsion system design that can decrease thrust specific fuel consumption (TSFC) relative to the TSFC of present engines in endurance aircraft. Gas turbine engines for long endurance are pushed in the direction of high cycle pressure ratio, high bypass ratio, and low flight Mach number during loiter, although freedom to vary the latter is severely constrained because of the need for high velocity to generate adequate lift at high altitudes, where the air density is extremely low.

The first question is engine type. The engines used for Tier 2+ are turbofans with bypass ratios of roughly 5. At this bypass ratio, lower TSFC (say 10% - 15%) has been achieved with higher cycle pressure ratio in large gas turbine engines for commercial aircraft, but these high pressure ratios have not been used in the smaller engines that would be appropriate for the UAVs discussed. Further improvements can be achieved by increasing the bypass ratio either in an ultrahigh bypass ratio (12-15) configuration or in an advanced turboprop.

There are several constraints on the engine design. For the penetrating endurance vehicle, a turboprop cannot be used since the blades must be shrouded. In addition, there is a size restriction on engine diameter, say 3 ft. For very high bypass ratios or high cycle pressure ratios, the core dimensions become much smaller than existing cores of high efficiency engines and the component efficiencies can be compromised.

It appears that for the proposed high altitude endurance UAVs, no existing propulsion system is well tailored. For gas turbine engines, no engine from the IHPTET program is optimized for TSFC at an altitude and Mach number consistent with the requirements of the two endurance UAV missions discussed. Several specific technology questions can be asked, even in the preliminary stages: If one designed an engine for an altitude of 70,000 ft and a cruise Mach number of 0.5 aimed at low TSFC as well as low manufacturing cost, what would it look like? What are the compressor and turbine configurations for these small engines that would best meet the mission goals?

In summary, considerable advantage could stem from design of an engine for UAV usage, but there are no current development efforts in this area.

4.2.3 UAV Structural Design

Some requirements/objectives unique to UAVs call for different approaches to structural design than those used in the past for manned vehicles. One of these is the increased need for integration of the different functions in a UAV to save weight and improve efficiency. The objective should be to achieve an empty weight fraction of 0.3. A second UAV objective is reduced cost, where the view is that many low-cost, possibly attritable vehicles with limited life are superior to small numbers of manned aircraft. The objective should be to produce UAV airframes at a cost of $500 per pound or less. A third requirement is maintainability and repairability, including readiness after long-term storage. A fourth objective is improved stealth to operate or penetrate through hostile airspace.

To achieve these objectives, the structural philosophy used to define loads and create structural forms must be changed from man-rated designs. The central point is that UAV structural design must be carried out in an integrated manner, rather than as a diverse array of stovepiped individual technology plans.

> *Changing Structural Design Philosophy* - Current design philosophy and loads criteria used for manned aircraft design are the result of 90 years of manned aircraft experience. The rules for defining critical loads have not kept pace with advanced technology capabilities, for example the arbitrary setting of the factor of safety at 1.5 (structural weight increases with an increase in the factor of safety). This value is historical and originally represented the ratio of the ultimate stress to yield stress of a type of aluminum no longer used in aircraft. Future UAV designs must develop a definition of loads and safety factors related to the mission to achieve a rational, scientific design philosophy for this class of vehicles, rather than pursue evolutionary adaptation of existing manned aircraft design criteria.
>
> *New Materials Integration and Construction Processes* - Composite materials, such as fiberglass and graphite tape and cloth, provide low structural weight fractions; however, the cost of manufacture of these materials can be high. Current quoted costs for aircraft composite structure are from $1,500 - $2,000 per lb; a near-term cost target for reduction of this should be $1,000 per lb. In addition to low weight, composite materials provide tailored surfaces for low

observability. Further, there is ample room for innovative (and integrated) design for more structurally efficient high lift to drag (L/D) configurations.

The "ility" issues (including repairability, reliability, and maintainability) are different for UAVs than for manned aircraft that are used extensively during peacetime. Further, limited special use provides fewer opportunities for "friendly" damage and tends to dictate consideration of different construction materials such as composites.

4.2.4 UAV Life-Cycle Costs

Among the motivating factors for accelerating the development of UAVs for military applications is a significant *potential* for life-cycle cost savings. This potential manifests itself not only through the low costs projected for a new class of unmanned airborne platforms, but also in the promise of reduced operations and support costs. In discussing UAVs, there is a tendency to focus on the vehicle and its constituent subsystems, but the affordability issue must be addressed in a larger context that encompasses the interdependent elements of vehicle, weapon, and a highly integrated command and control capability. This section recognizes the investment that will be made over time in command, control, and communication systems for battlefield domination and addresses the potential that results from harnessing this capability to maximize platform performance while minimizing cost.

Operations and Support Costs - The combat UAV, reflected in concepts such as the Uninhabited Combat Air Vehicle described in the study "New World Vistas[5]" or the Unmanned Tactical Aircraft proposed by DARPA, affords unique opportunities for affecting airpower affordability. The potential for operations and support savings may be realized through a new paradigm in training, maintenance, and deployment. The key to this potential lies in two observations:

1. Most noncombat flying occurs as a result of the need to achieve and maintain pilot proficiency.

2. Training to "operate" a UAV can be made transparent to whether or not a vehicle is actually in flight.

The latter implies that training in the simulator and training in the aircraft are identical in principle and suggests an operational concept involving substantially less flying than today's manned systems demand. It further suggests a leaner logistics 'tail,' including provisions for extended periods of aircraft storage and a concomitantly smaller team of maintainers, other support personnel, and infrastructure.   Recent studies, sponsored by DARPA and conducted by several organizations, including a major US aircraft manufacturer, have suggested cost savings potential approaching 90 percent overall in peacetime operations and support.

Storage of aircraft in a protective environment that permits rapid reconstitution of assets (minutes to hours) to meet wartime deployment or peacetime exercise requirements is a major and necessary part of the support concept. The study "Life Extension and Mission Enhancement for

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[5] United States Air Force Scientific Advisory Board Summer Study, *"New World Vistas: Air and Space Power for the 21st Century,"* 1995.

Air Force Aircraft[6]" addressed a "hermetically-sealed storage bag" concept that has been incorporated in recent combat UAV studies. Storage of aircraft in a dehumidified environment is a common practice by European air forces (Swedish, Danish, and British) as well as the United States Navy. In addition, the Swedish, German, and Israeli armies employ dehumidification storage for a variety of mechanical and electronic systems, including ground vehicles, with excellent success. In a recently released report[7] by the Logistics Management Institute, the benefits of dehumidified protection are clearly demonstrated.

The key to this result, and good news from a cost perspective, is the single requirement to maintain the relative humidity between 25% and 40%. Low-cost desiccant wheels can currently provide this environment on the flight line and under more permanent storage conditions. Flight line bagging, "clam shell" shelters, hangars, and special storage containers have all been combined satisfactorily with dehumidification systems in both operational and support scenarios. Storage for ease of maintenance, rapid deployment, and low cost appears to be readily available and will likely be used for both manned and unmanned aircraft in the near future. The study group spent considerable time examining the viability of the "wooden round" concept, especially as applied to existing cruise missiles, and was convinced that the idea had merit. The most important step is to build in this capability from the outset.

Another concept synergistic with extended aircraft storage is that of an "attritable" platform—a low-cost vehicle designed to take advantage of its limited life requirement. Aircraft built on this concept would be maintained and supported more like their expendable (e.g., missile) counterparts. This "quasi-wooden round" attribute also reduces the need for support personnel in peacetime.

Vehicle Acquisition Costs - While the largest potential for cost-savings remains in the new support concept, opportunities for savings also reside in the acquisition of these vehicles. The development and fielding of a smaller, less complex replacement for manned attack aircraft cannot be ignored. The reduction in size and weight directly attributable to the human crew and related subsystems is conservatively estimated at 5 percent. However, substantially greater weight savings will result from reduced load margins, elimination of man-rated components, reduced levels of redundancy, increased use of true composite structure (not just materials), extensive use of "more electric aircraft" components, and overall added simplicity.

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[6] United States Air Force Scientific Advisory Board Summer Study, *"Life Extension and Mission Enhancement for Air Force Aircraft,"* 1994.

[7] Logistics Management Institute White Paper LG518LN1, *"Using Dehumidified Preservation as a Maintenance Technology for DoD Weapon Systems and Equipment,"* McLean, VA., 1996.

4.3 PLATFORM SUMMARY

The study group organized its work around two distinctly different types of air vehicles for UAV applications: those that emphasize endurance and those that emphasize performance. Both categories have the potential to greatly improve the ability of the Air Force to execute its missions on behalf of the Nation.

The study group strongly believes that the current Tier programs for endurance air vehicles (Global Hawk, DarkStar, and Predator) are on the right course. Moreover, since they have ambitious goals in terms of their combinations of altitude, range, endurance, payload, and observability, these programs must be protected from external changes to maximize their chances of success. The current Tier UAVs have not been designed to accommodate weapons: addition of weapon carriage is likely to entail performance penalties and could disrupt these critical programs. However, advanced UAVs in these payload classes could be designed to be weaponized.

The future potential of unmanned aircraft extends beyond the baseline concepts presented in this report. Imagine the following types of UAVs, mention of which is intended to stimulate the reader to look beyond the near-term to the far future: a CONUS-based, hypersonic transatmospheric aerospace plane capable of overflying any location in the world and returning to base in less than two hours; a high altitude, global range, indefinite loiter VLO combat UAV; or a very large global range transport capable of providing emergency humanitarian aid without exposing an aircrew to danger.

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Chapter 5

Mission Systems and Enabling Technologies

5.1 GENERAL

The study group examined the functional requirements and enabling technologies for the electronic systems used by UAVs in performing operational tasks, with particular reference to the nine selected baseline missions/tasks. The analysis presented in detail in Volume II includes both assessment of the mission systems needed to perform the nine operational tasks that are the focus of this study and an overall evaluation of the state-of-the-art in key technology areas.

For each of the nine baseline operational tasks listed in Chapter 3, a mission systems package was defined and first-order functional requirements were derived. Details are given in Volume II, Chapter 4. Table 5-1 summarizes the mission system elements involved in each task. It shows both the extremely diverse range of UAV avionics needed for these tasks and the areas in which continued investment in technology development has high potential to improve the combat effectiveness and affordability of UAV systems.

UAVs can carry a very wide range of mission systems. These include virtually every type of airborne sensor, from area surveillance and target location to weather reconnaissance; communications and navigation systems for both UAVs themselves and service to customers; electronic countermeasures for self-protection and neutralization of hostile defenses; and support to weapons delivery from UAVs or other platforms. The study group broke out onboard processing, distributed function management, and integrated information management as separate technology areas because they are central to the effectiveness of UAVs in many operational tasks and they are among the most important areas in which continued investment in technology advancement and demonstration is critical.

A high-quality digital terrain data base and the ability to accurately and flexibly convert it to high-fidelity displays for human viewing are important in a number of ways to future applications of UAVs. Accurate data are essential for precision geolocation of targets from various kinds of sensors. Digital terrain maps (DTMs) may also be important in providing accurately surveyed reference points in a sensor image from which comparably accurate coordinates of other objects in the scene can be derived. The lack of good (Level 3 or better) Digital Terrain Elevation Data files for much of the world and the overall problem of maintaining high-quality DTMs for all areas of interest on Earth are challenges with which the Defense Mapping Agency is currently dealing. In addition, all UAVs, by definition, employ some form of remote or automated pilotage, so that the human operator is not in a position to actually see the ground over which the vehicle is flying.

One of the most important findings of this study, from the mission systems viewpoint, is that in most operational tasks, UAVs frequently should be employed in coordinated clusters (just as many manned aircraft are) rather than as independent platforms. The reasons for this are:

- Large aperture baselines can be obtained by cooperative receivers on widely separated platforms, achieving high directivity for tasks such as emitter location.

- Cooperative functioning of threat warning, jamming, communications, and other systems can greatly complicate an enemy's task in locating and targeting UAVs; e.g., an individual jamming platform that has been locked up by a threat system can be alerted to go silent while other jammers neutralize the threat.

Table 5-1. *Mission System Elements Required for Each Operational Task*

Mission System Elements	*CWMD*	*TMD*	*Fixed Target Attack*	*Moving Target Attack*	*Jamming*	*SEAD*	*ISR*	*Comm/ Nav Support*	*Air to Air*
Information									
Onboard Processing:									
• Data Processing	X	X	X	X	X	X	X	X	X
• Signal Processing	X	X	X	X	X	X	X	X	X
• ATC	X	X	X	X	X	X	X	X	X
Distributed Functional Management:	X	X	X	X	X	X	X	X	X
Integrated Information Management:	X	X	X	X	X	X	X	X	X
Sensor									
Radar:									
• SAR	X	X	X	X	X	X	X		
• MTI	X	X		X			X		
• Air-to-Air		X					X		X
• FOPEN		X	X				X		
EO/IR Sensors:									
• Imaging/FLIR	X	X	X	X		X	X		
• IRST		X							X
• LADAR/LIDAR	X						X		
• Designator	X	X	X	X		X			
• Laser Ranger	X	X	X	X					X
ESM:									
• Intercept/ Exploitation	X	X			X	X	X		
• Emitter Location	X				X	X	X		
Special Sensors:									
• Meteorology							X		
• Chem/Bio	X								
• Nuclear	X								
ECCM:									
• RF Sensors	X	X	X	X		X	X		X
• EO/IR Sensors	X	X	X	X		X	X		X
Communication									
Communications:									
• Data Links	X	X	X	X	X	X	X	X	X
• Relay/Switch	X	X	X	X	X	X	X	X	X
Navigation:									
• Positioning	X	X	X	X	X	X	X	X	X
• Target Geolocation	X		X	X	X	X	X	X	
• GPS Augmentation	X		X	X	X	X		X	
Other									
ECM:									
• Self Protection	X	X	X	X	X	X	X	X	X
• Escort/Area Jammer	X		X	X	X	X			
• Communications Jammer	X				X	X			
Fire Control									
	X	X	X	X		X			X

- Many UAV functions are more effectively performed at close range rather than from standoff to take advantage of the $1/r^2$ dependence of RF propagation and to reduce response times for time-critical targets; this implies use of multiple platforms to achieve area coverage.

- Separate platform concepts often allow higher value assets, such as high-performance sensors, to be less exposed to enemy threats, while those that must fly in harm's way can be made more attritable.

- Most ISR situations dealing with difficult targets (e.g., when the enemy uses cover, concealment, and deception) are best attacked through the use of one or more sensors to cue one or more other sensors and through fusion of multiple target signatures; practical design constraints dictate that multiple platforms will be used to carry this ensemble of sensing and information processing equipment.

The inventory of UAVs available in any operational situation is likely to be limited by economics, which could have an impact on an air commander's ability to deploy clusters as just described. However, sound design practices applied to payloads will do much to mitigate this concern. In particular, modular hardware and software will allow each available platform to be uploaded with the specific mix of functions needed in a given mission and will facilitate mixed payload functions (e.g., ISR collection and communications/navigation support on the same UAV). Then a platform which functions as part of a cluster for one activity (e.g., emitter location) could also work individually (e.g., as an imagery collector).

Another consequence of cooperative missions is that UAVs increasingly require robust, high-performance networking both for information exchange among platforms and for real-time interaction of human system operators, engagement controllers, and aircrews participating in a given mission. UAVs have high potential to enhance the effectiveness of the entire force structure by providing connectivity and interoperability among ground and air forces and by supplementing GPS with more jam-resistant navigation support for the growing number of systems that depend critically on GPS positioning. Collectively, these networking requirements place increased importance on C2 architecture and systems. The results of the C^3I Architecture Cell of this study (Volume II, Chapter 7) and of the concurrent SAB C2 Vision study[8] are thus extremely important adjuncts to the mission systems discussion.

In keeping with the overall sense that SEAD is an area of particular importance and one where valuable operational capability can be demonstrated in a relatively short time through exploitation of existing technologies, the study group devoted particular attention to the jamming and SEAD operational tasks. Specifically, it carried the requirements analysis and system concept description for these tasks to a relatively higher level of detail to support planning for a focused, near-term demonstration program aimed at an increasingly critical shortfall in our capabilities for electronic warfare.

5.2 ENABLING TECHNOLOGY STATUS AND REQUIRED DEVELOPMENT

An important overall finding of this study is that most of the enabling technologies required for these mission system concepts are in hand or in an advanced state of development. This is particularly true for basic UAV functions that focus on individual platforms. Most of the required developments concern technologies for higher levels of autonomy, including functions that require automated coordination of multiple platforms and systems. In particular, onboard digital processing and data storage will continue to experience dramatic improvements through leverage of huge investments in commercial technology,

[8] United States Air Force Scientific Advisory Board Study, *"Vision of Aerospace Command and Control For the 21st Century,"* SAB TR-96-02, 1996.

making increasingly processing-intensive system designs feasible. This trend extends to the gradual replacement of analog electronics, including those in RF and EO/IR systems, by digital processors. Table 5-2 summarizes the enabling technologies for the missions systems identified.

Table 5-2. *Summary of Enabling Technologies for UAV Mission Systems*

Mission Systems Element	***Enabling Technologies***
Sensors	
SAR/MTI Radar	Efficient, Broadband Solid State Power Devices Super-Resolution/ATC/ATR
Air-to-Air Radar	Lightweight, Low Cost, LO Apertures F-22/JSF Technologies Efficient, Broadband Solid State Power Devices
FOPEN Radar	Broadband UHF/VHF Power Sources Super-Resolution/ATR
EO/IR Passive Imagers	RFI/Jamming Mitigation Advanced Focal Plane Arrays
LADAR/LIDAR	Advanced Video Processing Techniques Compact, Efficient, Tunable Lasers
ESM/Emitter Location	Optical Phased Arrays Single-Chip Receivers Gigasample A/D Converters GPS Location and Timing References
Meteorological Sensors	Automated Signal Exploitation Multispectral/Doppler LIDAR Microwave Radiometry
Chem/Bio Sensors	Compact Dropsondes Active and Passive Multispectral EO/IR UV Fluorescence
Nuclear Sensors	UAV-Serviced UGS Chem Sensors for Nuclear Materials
Comm/Nav	
Data Links	ATC/ATR/Data Thinning Broadband AJ/LPI Waveforms Advanced Coding/Compression
Relay/Gateway Node	Network/Gateway Architectures Lightweight, Efficient Receiver-Transmitters Co-site Interference Mitigation
Navigation/Positioning	Tightly Coupled INS/GPS Guidance MEMS
Target Geolocation	Imagery Derived Location Improved Digital Terrain Data
GPS Augmentation	Available RF & Digital Technologies
Onboard Processing	Algorithms for Higher Levels of Autonomy Commercial-Derived Processors/Storage Advanced Analog-to-Digital Converters
ECM/Jamming	Microwave Power Modules Advanced Techniques/Jamming Waveforms
Fire Control	F-22/JSF Technologies Compact, Efficient Laser Designator

It is important to stress that the maturity of available technology is such that significant operational capability can be demonstrated and fielded in the near-term. To illustrate this point, Table 5-3 lists a number of system concepts which the study analysis identified as having high operational value and being well-suited to UAV platforms. For each, we provide an assessment of the timeframe in which a demonstration of mission systems leading to accelerated fielding of the system can be completed.

Table 5-3. *Recommended UAV Mission System Technology Demonstrations*

Operational Tasks	***Mission System Technology Demonstration***	***Near-Term: (1996-2005)***	***Mid-Term: (2006-2015)***	***Far-Term: (2016-2025)***
Jamming & SEAD	EW UAV Cluster w/ ESM, TDOA Emitter Location, & Smart Jamming	√		
ISR	ISR Sensors w/Onboard Image Screening	√		
Fixed & Moving Target Attack	Image-Derived Precision Target Geolocation	√		
Communications/Nav Support	Communications Relay w/ GPS Augmentation	√		
CWMD	Nuclear & Chem/Bio Remote Sensing		√	
TMD - Ballistic	IRST & Hypervelocity Missile Fire Control for BPI		√	
TMD - Cruise	UAV Pulse Doppler Radar & AAM Fire Control		√	
Air-to-Air	Air-to-Air Targeting and Weapon Guidance for Highly Agile Platform		√	
Other Missions	Advanced Technology Concepts			√

The clear message is that, in the judgment of the study group, much can be done in the near-term, while enhancements to yield still higher levels of performance and affordability can be incrementally implemented over time.

As Table 5-3 indicates, a number of technology areas require additional investment, including the following:

- Current UAVs are limited in their onboard functionality, e.g., image formation and data compression. The algorithmic basis for higher levels of autonomy is currently largely heuristic. Greater autonomy has enormous leverage for system performance and affordability. For example, a level of pattern recognition that allows real-time screening of imagery to select only content of interest for full resolution transmission to the user can dramatically reduce the required bandwidth of data links and thus the size and cost of data terminals and antennas. Other high-payoff functions are adaptive sensor operation including self-cueing, management of system resources and circumvention of failures, and support for the kind of cooperative functioning of UAV clusters that was described earlier in this chapter.

- Distributed function management is regarded as a technology in its own right, one that is, relatively speaking, in its infancy. Advances in spatially distributed processing, distributed sensing, automated management of multiple systems, and other aspects of the problem have high leverage on overall force structure effectiveness, mission planning, required data link capacity, and the complexity and workload of system operator stations.

- The capabilities enabled by UAVs greatly enrich the information sphere of the battlespace. Effective use of this information depends in large measure on progress in the technology of data bases, information access tools, truth maintenance across distributed data bases, human machine interfaces, and the like. While UAV systems can exploit the progress being made in these areas by the information industry, focused attention to information architectures and implementations that can meet the unique demands of UAVs will continue to be essential.

- Most UAV concepts require high survivability in the presence of enemy air defenses. A combination of methods will be required to achieve this capability. Continued investment in apertures with low RCS as well as in RF power management techniques and use of passive sensing modes like bistatic radar to reduce platform emissions are important elements. Furthermore, self-protection and cooperative multiplatform operating modes can limit required emissions and thus contribute significantly to survivability.

- A general technology theme for mission systems is maintaining present levels of performance while dramatically reducing size, weight, power consumption, and especially, cost. This area is rich with opportunities for high return on investment. Novel antenna structures composed of easy-to-fabricate sandwiches of layers with printed metallization and methods of packaging COTS components to survive the flight environment are just two examples. Again, the use of modular, open architectures is critical to affordable and rapid insertion of technologies to improve both affordability and performance.

- In a related vein, technology insertion for affordability can be effective in dealing with concerns about UAV attrition. Trade studies supporting the definition and selection of such projects should consider the operational payoffs of using UAVs more effectively because lower cost makes losses easier to accept.

In short, most of the technology portfolio for the UAV mission systems described in this report is low risk and targeted funding of high-leverage enabling technologies like those just listed can greatly enhance the robustness, affordability, and combat effectiveness of these systems.

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Chapter 6

Weapons and Warhead Technologies

6.1 MISSIONS AND WEAPONS

Of the nine mission areas identified in Chapter 3 as important baseline missions/tasks for technology analyses, six are weapon-carrying. The ideal weapons and warheads for launch from combat UAVs are delineated for each mission in Table 6-1. Some are existing missiles. In addition, three new missiles with modular warheads are envisioned for phased developments to fulfill a spectrum of combat UAV and manned aircraft missions: a small, planar strike weapon in the 100 lb class, a small kinetic energy penetrator, and a hypervelocity air intercept missile—all with modular warheads. A number of innovative, modular warhead technologies are the keys to achieving high capabilities in small UAV-compatible weapons.

Table 6-1. *Missions and Weapons*

	CWMD	***T/CMD***	***Fixed Target***	***Moving Target***	***SEAD***	***Air to Air***
Weapon	Kinetic Energy Penetrator	Hyper-velocity Missile w/IR Seeker	Dispenser, LOCAAS 3.5 in. Small, Modular Missile	Dispenser, Homing Missile (TOW, Hellfire, Maverick) 3.5 in. Small, Modular Missile	Dispenser, LOCAAS 3.5 in. Small, Modular Missile	AIM-120 AMRAAM AIM-9 Sidewinder Hypervelocity Missile
Warhead	Thermitic Sealant Foam	Kinetic Kill Vehicle w/ Divert Thrusters	Flying Plate Incendiary High Power Microwave	Wide Area Submunitions (CEB)	Flechette Incendiary High Power Microwave	Unitary/Self-Forging Fragments High Power Microwave

6.2 UAV FAMILY OF WEAPONS

The family of weapons proposed for UAVs use near-term technologies that have been demonstrated and are ready for implementation. The weapon required for boost phase intercept (BPI) of TBMs is unique in that it is a hypervelocity, hit-to-kill missile. The missiles required to perform SEAD, interdiction, hardened target destruction, as well as chemical warfare/biological warfare (CW/BW) neutralization may be of a common architecture with different warhead mechanisms. Alternative warheads such as the high-power microwave (HPM) or other mechanisms can be delivered by many existing platforms, depending on the threat requirement.

The resultant missiles required to undertake the six attack mission/tasks identified in Chapter 3 would fall into four basic classes:

- Hypervelocity missile with kinetic kill vehicle (KKV) payload for the BPI threat.

  Nominal Size: 500 lb, 8.5 in. diameter, 84 in. length, 2.5 km/s, 120 km standoff range.

- Kinetic energy penetrating missile for hardened target destruction and SEAD.

  Nominal Size: 75-100 lb, 3.5 in. diameter, 56 in. length.

- Low cost, low velocity cruising kill vehicle (LOCAAS-like) for a variety of interdiction missions.

  Nominal Size: 75-100 lb, 9.5 in. width, 30 in. length, 7.1 in. height.

- Air-to-air missions may not require a unique new missile. Current and upgraded versions of the Sidewinder (AIM-9) and AMRAAM (AIM-120) will meet envisioned near-term needs. If a kinematically superior airframe is required for the future, a derivative of the hypervelocity KKV should meet that need, provided a compromise in weight can be reached.

The following sections describe each of the three weapons that comprise the family of UAV weapons capable of the full spectrum of mission capabilities. The last section describes the recent innovations in the key warhead technologies that enable high lethality to be achieved with small, low-cost weapons.

6.2.1 Hypervelocity Missile

A new missile is required to attack TBMs when conventional missile technology is employed. The basic missile must have the performance capabilities described in Table 6-2. The study group proposes a near-term solution that combines existing non-developmental item (NDI) technologies and components (with a respectable 2.5 km/s [8,000 ft/s] velocity). In the early phase of flight, command-inertial guidance is employed. The KKV is deployed when the interceptor approaches the target intercept zone. The KKV employs an infrared seeker and divert thrusters to achieve a direct hit on the target.

Table 6-2. *Hypervelocity Missile Parametric Design*

Parameter	***Value***
Velocity (at intercept)	2.5 km/s (8 kft/s) minimum
Launch Altitude	>20 km (65,000 ft)
Time of Flight	20-60 sec
Intercept Altitude	20-80 km (65,000 ft - 260,000 ft)
Intercept Range	25-150 km (80,000 ft - 500,000 ft)
Total Missile Weight	225 kg (500 lb)
KKV Mass	25 kg (55 lb)
MWIR Sensor	3-5 microns

UAVs with payloads of 1,000 lb to 2,000 lb at altitudes over 60,000 ft could be excellent platforms to host a new hypervelocity missile for boost phase intercept. The high altitude provides a synergistic capability for the UAV's self-protection and sensor detection of missiles in the boost phase, as well as a relaxation of missile parameters such as intercept velocity, dome heating, and missile weight. In a complementary deployment, this system can obtain target acquisition and cueing information from the airborne laser (ABL) platform, which would be netted to the theater Mission Control Element (MCE).

Due to its high-velocity and high-altitude performance, the KKV missile will have significant alternative applications on conventional aircraft for attacking TBMs, air-to-air missiles, other aircraft, and high-altitude UAVs.

6.2.2 Kinetic Energy Penetrator

A kinetic energy penetrator, with a family of warheads as shown in Figure 6-1, offers a UAV the ability to accomplish a large number of combat tasks. A 3.5 in. diameter, 56 in. long, 75-100 lb, GPS or GPS-updated, inertially guided penetrator provides the ability to functionally kill CW/BW targets; potentially neutralize CW/BW agents; crater runways and destroy aircraft shelters; "sure kill" surface-to-air missile systems; destroy ballistic missile transporter-erector launchers; kill elements of the armored task force including medium tanks, armored personnel carriers, and self propelled artillery; as well as accomplish other combat tasks.

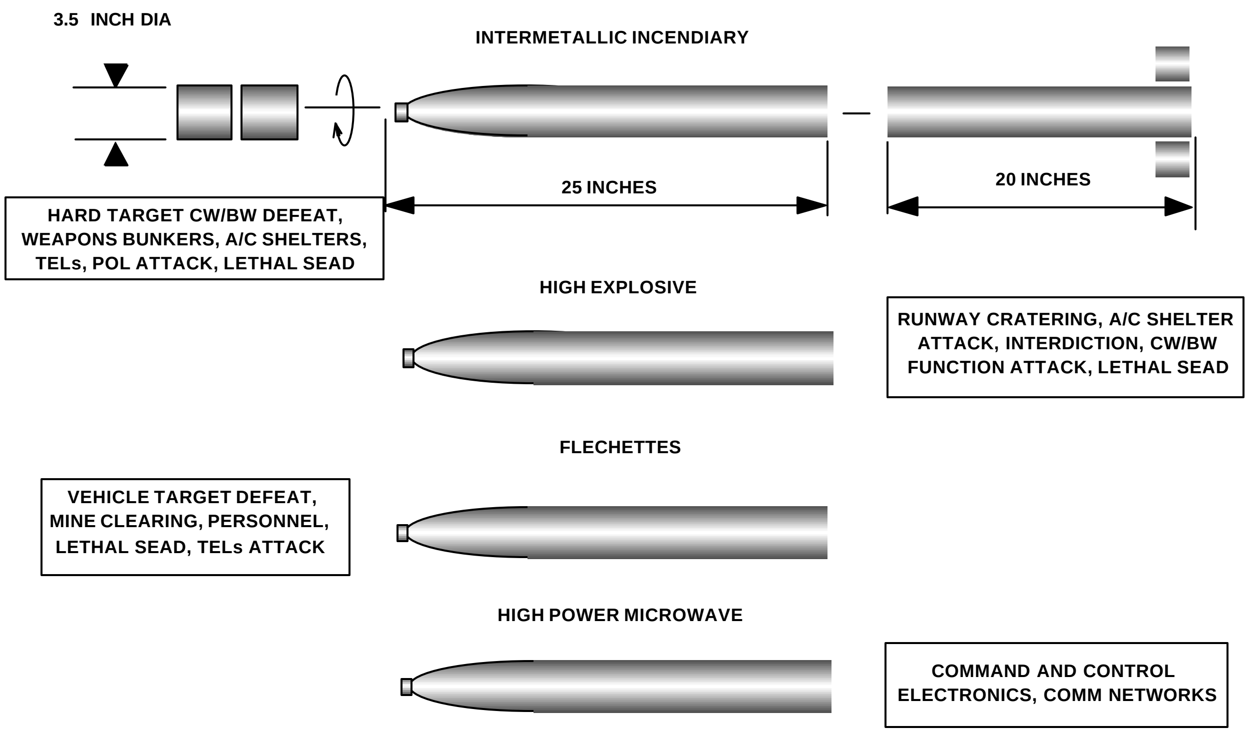

Figure 6-1. Kinetic Energy Penetrator

The kinetic energy penetrator is designed to deliver a CL-20[9] high explosive warhead with the ability to generate up to 450 kbars of detonation pressure, an intermetallic incendiary warhead capable of generating 3700°C firestorms, flechette warheads capable of penetrating many targets, or HPM warheads capable of upsetting, disrupting, and destroying electronics and communication equipment. These warheads would be modular and provide the kinetic energy penetrator with a family of lethal mechanisms that would enable it to accomplish a large number of combat tasks.

[9] CL denotes a China Lake-developed warhead.

The utility of the kinetic energy penetrator is enhanced by its ability to penetrate into and destroy buried and hardened targets such as aircraft shelters and hardened CW/BW facilities. A UAV attack on a hardened CW/BW facility would involve the delivery of a large number of penetrators against the target. The GPS receivers in the penetrators would be activated and the preselected GPS satellite information would be transferred to each penetrator. The penetrators would be dropped from medium altitude—typically 15,000 ft to 25,000 ft—and would guide to individual and separate points 2,500 ft over the target. Their terminal velocity of 1,200 fps to 1,300 fps would be increased to 3,000 fps by a rocket motor ignited at that point. At that velocity, the weapon could penetrate the equivalent of 20 ft of reinforced, 5,000 psi concrete or 250 ft of compacted soil. Upon penetration into the target, a deceleration-sensing fuse would sense the entry of the penetrator into a room, and the warhead would be detonated.

A titanium-boron intermetallic incendiary warhead would be used to incinerate agents within the room. In the case of hard target facility destruction, the deceleration-sensing "smart" fuse would sense the penetration into the structure, where a CL-20 high explosive warhead would be detonated. Several hundred penetrators would be delivered against an underground facility. Other targets could be engaged and destroyed by the kinetic energy penetrator delivering warheads tailored to the targets being engaged.

6.2.3 Low Cost Autonomous Attack System (LOCAAS)

LOCAAS, at this point a technology program with an uncertain future, is a small (<100 lb), highly lethal (P_{ssk}=0.8) munition capable of autonomous target acquisition and classification. It integrates "adaptable warheads," which give it a capability against a wide range of target types. In addition, LOCAAS could deliver a small flying plate warhead. Currently, a single-warhead package can be effectively employed against the full range of material targets from light trucks, relocatable targets, and surface-to-air missile installations to heavy armor. LOCAAS will reduce the payload weight carried on aircraft and UAVs for classical air power missions, such as interdiction, close air support, and SEAD. The long-term impact will be to allow future UAVs to be smaller, lighter, and less expensive. The small size of the individual munitions is consistent with internal carriage and dispensing associated with low-observable UAVs.

LOCAAS munitions utilize a unique seeker technology based on the development of a low-cost, solid-state diode pumped laser seeker. Captive and free-flight testing of the LADAR seeker has demonstrated a 99% probability of acquiring mobile or relocatable targets with a 95% probability of classifying the targets in real time. Currently, the algorithms utilize the range and angle-angle data for target acquisition and classification.

Future improvements are required to increase the range of the seeker by increasing the laser power output and the pulse repetition rate. At a nominal velocity of 330 km/hr and a 9:1 glide ratio, this equates to a search area of 1 km x 3.3 km. Ranges in excess of 5 km have been demonstrated to date. Similarly, the wavelength of the laser must be increased from the nominal 0.87 microns to something beyond 1.6 microns for eye safety and better all-weather performance.

The ability of the LADAR seeker to classify targets reliably has prompted the development of adaptable warheads to better couple the warhead energy to the target in order to maximize the probability of kill (P_k). A powered version to provide standoff and survivability for the launching platform is being considered. Further warhead improvement will ensue as precision warhead initiation systems and higher energy density materials become available.

6.2.4 Air-to-Air Missile

Currently envisioned UAVs will have a useful air-to-air capability that is limited by the size and weight of the missile load and the acquisition range of the UAV sensors. Consequently, the Sidewinder and AMRAAM families of missiles are projected to be appropriate weapons for the near- and mid-term applications. At such time in the future that growth of the UAV vehicle and sensor avionics (on and offboard) justify it, the superior kinematics of the hypervelocity missile could be employed.

The Sidewinder (AIM-9) is a family of IR dog-fight missiles weighing approximately 190 lb to 205 lb. The UAV must provide target bearing for seeker lock-on and fire control inputs such as in-range and identification friend or foe (IFF) indications. Some versions require a gas bottle for detector cooldown. The AMRAAM (AIM-120) is a family of radar guided medium-range missiles weighing approximately 340 lb. Sensors and avionics on the UAV must provide target vectors, IFF, and post-launch updates for command-inertial midcourse guidance.

6.3 WARHEAD TECHNOLOGY

Ideal weapons for delivery by UAVs are dependent on precision guidance and control and new warhead technology. Recent advances in novel warhead technologies enable small weapons to neutralize a wide range of hard targets effectively.

6.3.1 Flying Plate Warhead

The Naval Surface Weapons Center (NSWC) Indianhead Arsenal, MD, has defined and demonstrated a flying plate warhead that drives a copper disk toward the target with its flat face perpendicular to the direction of flight. The design, using a rubber buffer layer on the back of the disk, couples 40% of the explosive energy into the plate. The flying plate, upon impact with reinforced concrete, can be designed to "core" a hole completely through the target several times the diameter of the disk or to transfer its impact energy to reduce the concrete target to rubble. It also can be employed to perforate steel targets up to a few disk diameters in thickness. The warhead provides the ability to destroy bridge piers, drop structural elements, penetrate bunkers and accomplish other combat tasks.

6.3.2 High-Explosive Warhead

The new energetic, high-explosive warhead delivering a CL-20 explosive provides the ability to generate pressures up to 450 kbar. CL-20 can incorporate the explosive power of much larger warheads into very small warhead configurations. The warhead can be used for function kill in CW/BW facilities and to crater runways, destroy aircraft shelters, and damage other targets.

6.3.3 Intermetallic Incendiary Warhead

NSWC defined and demonstrated a titanium-boron intermetallic, self-propagating, high-temperature, synthesis reaction warhead capable of generating a reactant cloud at 3700°C. The warhead releases extremely large amounts of energy, providing the means to incinerate a variety of targets. Its fire-start capability is such that, once initiated, the fire cannot be quenched. When water is employed to quench the fire, the reaction disassociates the water into hydrogen and oxygen, and a secondary reaction forming oxides of titanium and boron releases additional energy to enhance the firestorm capability of the warhead.

The warhead has the ability to destroy aircraft shelters and conventional buildings and damage other targets and offers significant promise of neutralizing biological and chemical agents.

6.3.4 Flechette Warhead

The terminal velocity associated with many of the weapons that can be delivered by UAVs is high enough to allow effective use of 500-600 grain flechettes that are capable of inflicting multiple penetrations of the target. The warhead can be used to disable combat vehicles and "sure kill" enemy air defense sites, transporter erector launchers, and other targets.

6.3.5 High Power Microwave

HPM technology uses repetitive pulses or single-pulse concepts. The warhead, for example, can use an explosively driven flux compression generator to power a single "shot" HPM warhead capable of upsetting, disrupting, and destroying electronics. Concepts exist, employing new microwave circuits, solid state switching arrays, and impulse radiating antennas to generate both narrowband and ultrawideband pulses on a repetitive basis. The warhead can be used to destroy command, control, and communication centers and electronics facilities.

6.4 WEAPONS SUMMARY

Achieving lethality with small weapons capable of being carried on small combat UAVs requires precision guidance (in most cases) and lethal small warheads. Ongoing technology programs appear to be providing a variety of precision guidance options. Some are in the inventory now. With the advent of some innovative wide kill-area warheads, hardening Air Force guidance systems appears to be the greatest technology requirement. For example, many missile guidance needs can be fulfilled with a reliable (jam-resistant) 30 ft circular error probable (CEP) GPS guidance system.

A number of innovative warheads have demonstrated capabilities that suggest UAV size-compatible weapons could achieve high lethality against difficult targets:

- Thermite warheads that achieve 3,700°C firestorm temperatures. These titanium-boron intermetallic warheads provide high destructive power and may approach the temperatures needed to neutralize CW/BW agents,
- Small flying plate warheads that destroy large, reinforced concrete structures,
- HPM warheads capable of neutralizing electronics at great distances.

These warheads have been demonstrated on "shoestring" budgets. As the key enabler for next-generation UAV (as well as aircraft) weapons, they should be supported with adequate funding to refine the understanding of the phenomenology, quantify their effects, and develop fieldable weapons.

Ongoing technology in combination with technologies identified in this report could enable relatively low-risk development of the family of weapons to meet the needs of the six weapon-carrying combat UAV missions.

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Chapter 7

Human Systems[10] and Enabling Technologies

7.1 ROLE OF THE HUMAN IN UNMANNED AIRCRAFT OPERATIONS

The role of the pilot in traditional aircraft is fundamentally to "aviate, navigate, communicate, and operate." That is, the pilot is responsible for maintaining the aircraft thrust and attitude to remain in flight or transition to takeoff and land, directing the aircraft on the intended path to get to the desired destination, communicating his intentions and receiving information from others, and performing actions necessary to maintain the subsystems in the appropriate state. Some people have tended to lessen the importance of human operators with respect to UAVs because many, if not most, of the functions will be automated. Several considerations indicate that rather than being reduced in importance, the human and the design of systems for human use are every bit as important, perhaps more important, with automation. Among the arguments supporting this contention are the following:

- No one can anticipate all events that may occur during flight. Malfunctions, retasking, enemy actions and countermeasures, intrusions by friendly forces, and other events may call for mission replanning or other intervention by the controller.

- The human may have a limited time to respond. Unless situation awareness has been maintained, the ability to make the appropriate response in the time available could be compromised. Moreover, the operator will be missing many of the cues present in manned aircraft.

- Automated systems customarily handle the easy tasks, leaving the more difficult ones for the human.

- Experience with other automated systems (such as commercial aviation, nuclear power plants, oil refineries, and other endeavors) indicates that a human operator is still required to make automation effective, although the nature and frequency of the tasks required to meet the objectives may differ.

- Inevitably, the human is still responsible for the successful accomplishment of the mission.

In short, the human is not replaced by automation but is freed from simple and boring tasks to accomplish those functions most suited to human intellect.

UAVs now in operation or in development have few similarities in the allocation of tasks to the human and the degree of autonomy allocated to the automatic systems. The DarkStar program philosophy is to

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[10] Some definitions are in order for clarity:
Human Systems - The elements of a system, including airborne and ground hardware, software, environmental control, and procedures for which design should consider human characteristics such as workplaces, communications systems, environmental control, maintainability features, personnel selection processes, training, etc.
Human Factors (also Human Factors Engineering) - The multidisciplinary vocation or field dedicated to discovering, understanding, and applying information about human characteristics, including strengths and weaknesses, to the design of a system. May include psychologists, physicians, physiologists, anthropologists, sociologists, engineers, and mathematicians. Involves physical size and strength, motivational factors, effects on emotion, etc.
Human System Interfaces - Those facets of a system with which the human directly interacts, such as displays and controls, seating, protective garments, etc.

automate everything from taxi through the entire mission. Predator requires manual landings and takeoffs. Some systems were designed to require a trained pilot; others made the assumption that automation would enable a relatively untrained person to operate the system, with analogies to a truck that any soldier could operate. These decisions were based on the assumptions of designers and other decision makers.

There are many good reasons automation should be implemented. Elimination of the human from an important role in UAV operation is not one of them. The human has many capabilities that are unmatched by any automatic system currently foreseen. Automation will not eliminate human error but will relocate it to preflight activities and the remote human operator position.

The reliability of digital systems is uncertain in benign environments, let alone in a war in which an intelligent enemy is trying to thwart the mission. Although failure mode and effects analyses can be conducted, they are impossible to perform on multiple failures because the number of possible events (and combinations) rapidly becomes prohibitive. As mission complexity increases to include combat missions, flying mixed fleets, and multiple UAVs the potential for automation error grows. The human's flexibility and capability for inductive reasoning are desirable attributes that justify the retention of a significant supervisory and intervention capability during UAV operations for the foreseeable future.

For the reasons stated above, the study group concluded that trained and proficient pilots should man the mission control elements and have the capability to intervene in mission and flight operation. This approach should be reviewed as experience in automated flight/mission operations is gained.

Table 7-1 lists several categories of human-machine interaction. Too often, the assumption is made that everything that can be automated should be fully automated to reduce human workload and error. Little emphasis is placed on making carefully considered decisions based on well-defined criteria and data to establish the degree of automation as shown in the table, function-by-function. In the UAV aircraft programs reviewed during this study, there was little evidence that human factors specialists had participated substantially in the design phase of any of these programs.

7.2 HUMAN SYSTEMS TECHNICAL ISSUES

A number of technical issues are critical to future UAV operations. These issues must be addressed at the technology base level, as well as applying available mature technology at the UAV design level.

7.2.1 Allocation of Functions

Assignment of appropriate roles and functions between the human and automated components of the system is vital for successful design. The human, the software, and the hardware integrate to become one system and must interact effectively if missions are to be accomplished with the greatest efficiency and lowest cost. Criteria based on factors such as probable success, response time available, cost, and the status of technology should be established. Analyses of the relative strengths and weaknesses of alternatives can establish a baseline. For example, under normal mission circumstances authorization to release a lethal weapon may be reserved for the human. For ballistic missile intercept during the boost phase, it may be decided that the automatic system has the authority due to time constraints and the inability of the human to respond in time for a successful intercept.

Table 7-1. *Categories of Human-Machine Interaction*

Category	Description
Manual	Unaided manual activity as in assembly, maintenance, servicing, or in operational control of a vehicle or system.
Augmented	Amplification of human sensory or motor capabilities with powered assists, sensing devices, etc.
Tele-operated	Use of remotely controlled sensors and actuators allowing the human presence to be removed from the work site, e.g., remote manipulator systems, tele-operators, tele-factors, etc.
Supervised	Replacement of direct manual control or tele-operated control of system operation with computer directed functions as though maintaining humans in supervisory control.
Independent	Self-actuating, self-healing, self-learning independent operations dependent upon automation and artificial intelligence and minimizing the requirement for direct human intervention.

This baseline can be tested in several different types of simulations, including computer modeling and human-in-the-loop, to validate or define deficiencies. The DARO/DARPA Warbreaker program has used this process and serves as a useful demonstration of a simulation-based design process (see Simulation section below). A program should be established to formalize a rational approach to guide function allocation at the earliest possible phase of concept definition. This program is anticipated to be a process for defining meaningful and useful criteria, as well as establishing a baseline for simulation to validate and support redesign.

7.2.2 Simulation

Simulation has many important roles in the development and introduction of UAVs to the Air Force:

- Development Tool - UAV design, crew station (mission control element) design, knowledge base development and testing, reasoning design, etc.

- Effectiveness Analysis - Utility, effectiveness, and survivability analysis for single flights, multi-UAV missions, mixed manned-unmanned aircraft missions, engagement, and campaigns.

- Training and Proficiency - Normal and emergency conditions simulation as well as response analysis, perhaps as an integral element of the mission control element.

It is important to recognize the differences as well as the similarities and synergisms between these various applications of simulation.

Most engineering disciplines rely heavily on testing during development to assure designs are acceptable and/or to optimize design. For human system design, simulation is analogous to wind tunnels for aerodynamicists or structural tests for structural designers. Human-in-the-loop simulation has been used in crew station development for many years. Simulation has been applied primarily to assessing handling qualities, display and control concepts, and crew station configuration. For piloted vehicles, concepts have involved tasks that were largely evolutionary. Although experiments conducted have been mostly part task, full mission simulation was used late in programs for demonstrations and/or for training prior to first flight.

While highly automated UAVs impose revolutionary changes on the nature of the crew tasks, effective use of simulation can help address key front-end human system issues, such as the role of the human, workload and staffing, display and control concepts, and general problems of crew station layout as well as concept of operations, command and control, etc. Several recent developments make this feasible, including:

- Rapid prototyping capabilities in which software can be in hand or quickly developed to represent and drive representations of many real world events at a relatively low cost.
- The development of Distributed Interactive Simulation (DIS) which allows many players at different sites to participate in many different scenarios involving HITL in both offensive and defensive roles.
- The availability of many already developed software programs for maps, weather, terrain, and other elements of scenarios generated for training simulations including battle management training.

The effectiveness of the human is vital to system performance. Human-centered design is worth the effort and cost. Simulation has great value in developing and validating human system design. Its application early in the process can make important contributions to design. Although some may believe its costs are prohibitive early in design, actual cost savings may be realized by early identification of system deficiencies, resulting in fewer engineering changes (a notorious cost driver) and lowered operational costs.

The advent of battle management simulation and DIS offers the opportunity to apply simulation to analyze and experience how a new concept could affect the outcome of battle. These effectiveness simulations are crucial to assess the cost-benefits for UAV and UAV- manned air forces and to determine the best mixes.

7.2.3 Human Performance Measurement

Decisions about the human role in systems should be data driven, not assumptions driven. Simulations are valuable even if only subjective opinions or observations are obtained. They can be far more valuable if data are obtained based on actual performance of the human. Performance on many psychomotor tasks can be directly measured. Since many of the tasks in automated systems will be decisions, often open-ended, it might be assumed that measurement of performance on these tasks against a rigorous standard may be impossible or at least very difficult. This may be true for some tasks particularly in the dynamic air-to-air arena.

It is believed, however, that suitable measurement methods may be devised if sufficient attention is dedicated to the task. Aircraft handling qualities, for example, consist of a number of variables that have many interactions. For years, assessments were left to vague test pilot descriptions. In the 1960s, Cooper and Harper developed a rating scale to introduce some rigor. This scale not only provided a better assessment tool but also facilitated research to foster a better understanding of system requirements. It is believed such rating scales could be developed to assist measurement for many if not all complex and/or subtle human decision making activities. Such measurement would help define human system design requirements, assuring that requirements are met and that effective training programs are developed and applied.

While the study group has strong reservations about the feasibility of totally replacing the human for many missions in the near-term, there is no denying the increasing potential for AI. The development of valid and reliable human performance measures would also further the development of AI models and provide assistance in deciding which tasks can be adequately performed by automated systems.

7.2.4 Command, Control, Communications, and Intelligence (C^3I)

Successful utilization of UAVs requires their integration with other Air Force operations, including the associated C^3I system. Positive control of UAVs is required to assure conflict with other friendly aircraft is avoided. These concerns become increasingly serious as the role of UAVs grows into combat missions possibly involving mixed fleets and multiple UAVs. Mission planning systems are vital for mission success, and this technology needs to be enhanced if UAVs are to operate with needed C^3I connectivity. Architecture concepts such as "layered cueing" and "collaborative operations" show promise for maximizing the military effectiveness of UAVs. Complex scenario-based simulations will be a powerful tool in developing and testing such C^3I concepts.

7.2.5 Vulnerability¾ A Human Systems Perspective

The three components of the system—the vehicle, the ground station, and the data link—are all vulnerable to attack. Direct attack may be made against the vehicle or the ground station. Misinformation may be introduced into the onboard systems through decoys and/or camouflage. Data links may be broken or noise introduced. If the operators' situational picture or ability to intervene is too limited, they will be restricted in response alternatives. Perhaps most important is the potential inability of the human to quickly process, interpret, and appropriately distribute all of the relevant information to the warfighters. This inability should be carefully assessed and investment to overcome shortfalls should receive a high priority. The Air Force is also encouraged to assure that system vulnerabilities are identified and addressed in the ongoing development of these systems so that their effectiveness is not unnecessarily compromised by enemy action.

7.3 HUMAN SYSTEMS NONTECHNICAL ISSUES

7.3.1 Attention Given to Human Systems Issues

The experience of a number of study group members is that developers generally try to give the customer what is sought within the constraints imposed. Air Force directives have historically imposed a requirement for a human factors engineering effort for major programs. Too often this requirement has been compromised, either in the interest of cost savings or because firm contractual performance requirements for human system performance were not specified. A June 1994 Air Force Inspector General audit of compliance with DoD 5000.2 (Human Systems Integration) found that only 3 of 110 programs reviewed were in compliance. This suggests that the Air Force seldom receives a well-designed human systems interface.

Where performance criteria have been established, such as in handling qualities, great effort is dedicated to assuring the requirements are met. The study group believes that lack of specified performance data and rigorous adherence to implementing a comprehensive human factors program and test plan have significantly reduced the contributions of the discipline and thus operational effectiveness. Moreover, these failures have resulted in added training time to meet operational performance standards and increased maintenance and logistical costs of fielded systems.

In some respects, this is a more serious problem for UAVs than for conventional manned aircraft. If appropriate displays are not provided, the operator will be denied adequate situation awareness, as the sensory-perceptual cues provided by direct vision, motion, or sound may not be available. Even if some of these cues are provided, the remote operator will likely be restricted in other ways and may suffer from time lags. If the potential need to intervene is not recognized and designed into a UAV, the remote operator will not be able to take action unless he or she is ingenious enough to invent a "workaround" (e.g., waypoint manipulation). Situation awareness will be difficult to maintain if the crew suffers from boredom, "automation complacency," overconfidence, or if the crew is replaced during the mission to avoid fatigue.

7.3.2 Manpower, Personnel, and Training (MPT)

MPT issues have been largely sidestepped by the ACTD programs. Contractors have been responsible for providing operators and support personnel during the developmental phases. But in future operations, military manning will be used. For the relatively benign reconnaissance missions, the resulting problems are probably manageable. For future missions, particularly those that involve mixed fleets, combat applications, and lethal weapon release the responsibility, skill, aptitude, and training requirements may be quite different. Unless this difference is addressed during acquisition, serious disruption could result.

A number of important issues must be addressed including selection criteria, rank of the differing personnel positions, staffing, and training requirements and processes. Ideally, MPT program development should be initiated during aircraft system development to assure a timely and effective employment of the system. The rapid acceptance and employment of the Predator UAV has highlighted some personnel and training problems. Attention should be given to finding methods to establish the MPT base to facilitate the transition of ACTD programs to fielded systems.

7.4 TECHNOLOGY REQUIREMENTS

The most pressing needs to foster effective human systems for UAVs are *process* improvements such as the following:

- Increased emphasis on human systems issues, beginning with the concept development phase with specific, measurable human performance requirements appropriately weighted and included in contracts.

- Development and implementation of effective and reliable methods, including analyses and simulation, to support decisionmaking about the role of the human, function allocation, and degree of autonomy assigned to automated systems.

- Definition and implementation of an improved transition process to facilitate rapid and effective deployment of systems developed using the ACTD approach.

- Identification of problems during the ACTD so they can be eliminated in production programs. Many accidents and incidents have occurred, however there seems to be no central repository to organize the data and/or to develop lessons learned. Such a process should be implemented involving all of the Services and developers. (Much of the UAV information obtained during this study was anecdotal).

Desirable technology improvements involve a number of areas:

- Digital technology and sensor developments have made many relatively new display and control concepts possible for manned aircraft such as helmet mounted displays, low-light level television, pull-down menus, and “look and shoot” systems. While human systems integration (HSI) issues still need to be addressed with regard to these media—such as improving resolution or reducing weight—most of this technology can be readily adapted as required to UAVs. A new technology that may have applications for UAV requirements is Virtual Presence. Considerable effort has already been devoted to developing this technology, but its value has not been convincingly demonstrated and many technical problems remain if it is to be used in real-world applications.

- No matter what display medium is used, there is a continuing problem with developing formats that will enable the operator to quickly assimilate and integrate large quantities of sometimes disparate information to achieve full situation awareness and to make rapid, accurate decisions. Significant support is required to develop display principles to facilitate the invention of such formats.

- An improved understanding of human information processing and decision making processes and weaknesses will facilitate better display formatting, training, and development of decision aids. This area, known as cognitive science, is closely related to artificial intelligence (AI) and should be supported aggressively.

- Development of metrics for assessing human performance in complex tasks would greatly benefit not only systems development but also training.

- The importance of simulation suggests that developments to increase its fidelity and reduce costs should be supported.

- A continuing need exists to process and transmit large amounts of data. Although this is not a problem unique to human systems, advances in this area would undoubtedly benefit UAV human systems applications.

- AI offers promise for developing decision aids and assuming first-order responsibility for many low-level, rule-based decisions. It is already being applied in a number of areas; additional advances will broaden its applicability.

- C^3I is a primary concern, particularly as mixed fleets involving many UAVs become operational. Architectures must be developed that will enable the required information to be available to anyone who needs it without delay. Human systems issues abound in this area also.

- UAVs will be vulnerable to direct attack on the vehicle, to the introduction of “misinformation” into the system by various methods, and to attack of the control element. Vulnerabilities should be systematically defined and appropriate precautions taken during UAV human systems design and operation.

7.5 HUMAN SYSTEMS SUMMARY

The Air Force should take action to identify appropriate processes that emphasize human-systems interaction issues and performance criteria to ensure critical functions are specified as contractually obligatory. One approach might be to organize a team of Air Force operational and laboratory specialists with industry representatives during the pre-proposal phase to define key automation and human systems issues and measures.

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Chapter 8

Example Point Design - Suppression of Enemy Air Defenses

In order to quantify the sensitivity of UAVs to potential technological advances and to define promising UAVs as precisely as possible, several preliminary design analyses were carried out during this study. One of the most important of these, SEAD, is described in this section, which is intended to serve as a departure point for more detailed examination.

8.1 SPECIFIC TASKS AND SYSTEM DEFINITION

A SEAD mission was selected to serve as a basis for preliminary combat UAV sizing studies. The mission goals were 800 nm of penetration with a 6 hour loiter capability. The mission profile is shown in Figure 8-1.

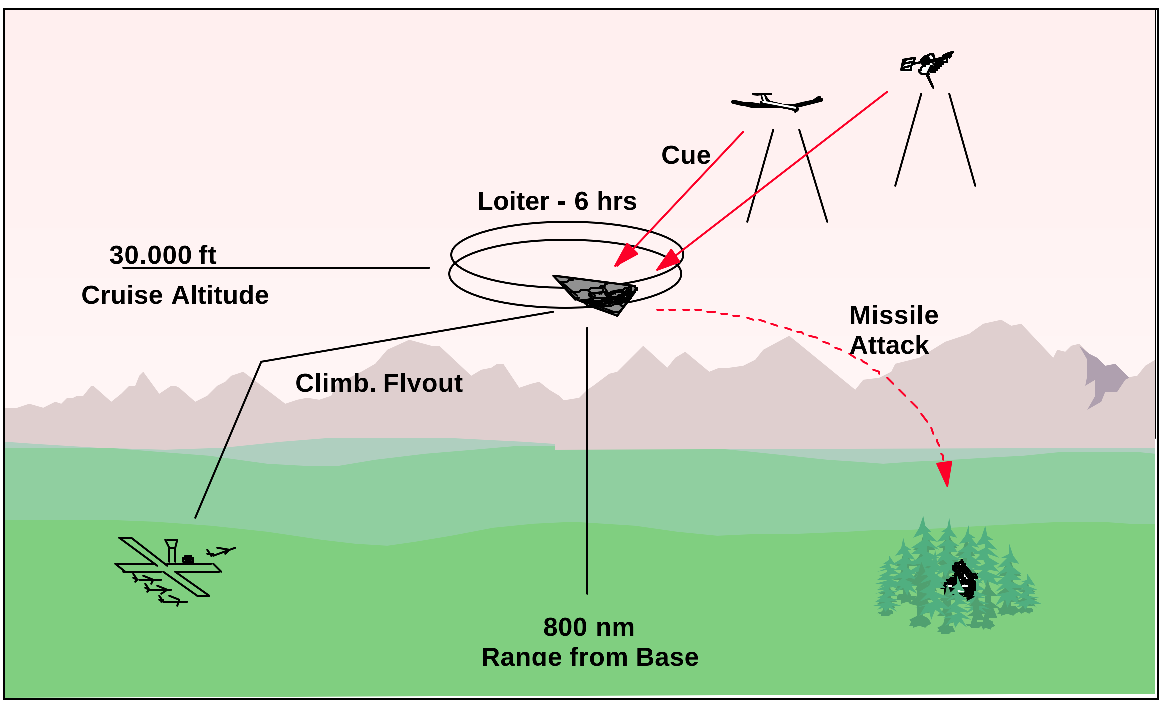

Figure 8-1. *SEAD Profile*

The mission is a cooperative one, with an ISR UAV providing the data so that target locations (GPS coordinates) are communicated to the SEAD UAV. The SEAD UAV cruises 800 nm to the target area and loiters for up to 6 hours, during which time it is cued to target(s) and launches a missile or missiles as authorized by the appropriate C^2 activity. The missiles have a range of approximately 5 nm. Eight 100 lb (see Volume 1, Chapter 6) missiles are carried on the UAV so that several targets can be destroyed. The UAV incorporates low-observable antennas on both wings for communication and control and carries onboard electronic countermeasures (ECM). Provisions for a limited number of expendable decoys are also included. The UAV has the capability to descend to 200 ft for attack if needed, at the expense of some loiter time.

8.2 DESIGN DESCRIPTION

Based upon the preliminary studies, a wing loading of 90 lb psf was chosen. Two weapon bays are located on either side of the engine, incorporating four advanced missiles in each. The main landing gear is located outboard of the weapon bays. Avionics compartments are located out on each wing: they are 5 in. deep for the electronic receivers and transmitters as well as the antennas. The engine has cycle characteristics similar to the existing Allison 3007 but scaled to the thrust necessary to carry out the most demanding phase of the mission.

The configuration selected has a trailing edge sweep of -15^{o} and a leading edge sweep of $+45^{o}$. While this moves the trailing edge radar spike close to the flight path, it is felt that adequate mission flight planning will make it acceptable. Good balance and volumetric efficiencies are possible with this design. Both the inlet and nozzle are on the bottom with serpentine ducts for low observability. The top surface is smooth for signature treatment. The vehicle cruises and loiters inverted to shield inlets, doors, and exits from ground radar. Note that the wing span of 22 ft was chosen to allow the UAV to be transported on existing aircraft, thus simplifying its deployment. Figure 8-2 below shows the notional configuration.

Figure 8-2. *SEAD UAV Configuration (Notional)*

8.3 TECHNICAL ANALYSIS

8.3.1 Aircraft

With respect to the small missiles, it was initially assumed that the vehicle would have a 7,000 lb takeoff weight. However, this vehicle achieved just over 3 hours of loiter at 800 nm radius. Larger vehicles were designed with loiter times shown in Figure 8-3 as a function of takeoff gross weight. The vehicle weighing

13,500 lb provided the desired 6 hours loiter time. (The shape of the curve indicates that this is pushing the state-of-the-art). The missiles were not fired, but carried home for these performance calculations.

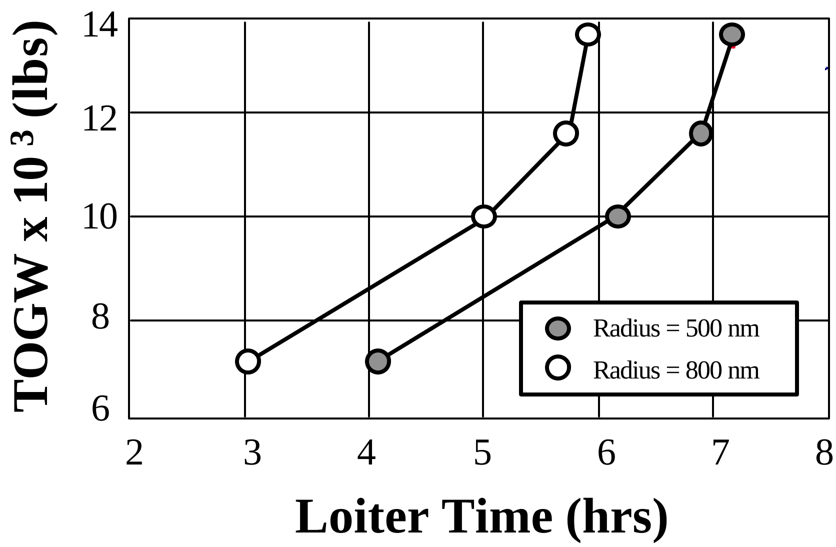

Figure 8-3. *Loiter versus Weight Trades*

The loiter time variation for the selected vehicle with radius is shown in Figure 8-4.

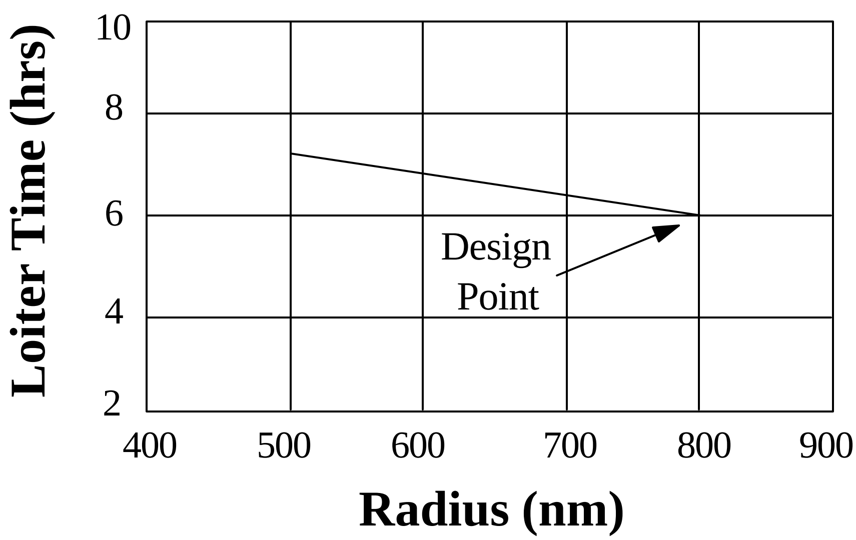

Figure 8-4. *Loiter versus Radius Trades*

The selected design has the characteristics shown in Table 8-1.

Table 8-1. *SEAD Aircraft Characteristics*

Characteristics	
Wing area	153.4 sq ft
Span	22 ft
Length	13.95 ft
Aspect Ratio	3.155
Engine	
Static thrust	3,700 lb (fixed geometry)
Diameter	19 in.
Weights	
Structure	4,500 lb
Engine	675 lb
Landing gear and subsystems	610 lb
Mission systems	400 lb
Fuel	6,515 lb
Weapons	800 lb (8 internal @ 100 lb ea.; no external)
Total TOGW	13,500 lb
Signature	Low-observable treatment for low- and high-frequency RF Tailored IR signature control
Storage	20 years
Deployment	C-5 or C-17

8.3.2 Mission System

The SEAD UAV requires minimal mission systems because it receives primary targeting information from offboard precision emitter location sensors. The functions that the onboard avionics must provide, in addition to basic vehicle operation and the command data link, are:

- Precise platform navigation via GPS-aided inertial navigation system (INS).
- Data link with TADIL-J class capacity and LPI/AJ features; transmissions in threat areas will be power managed and highly compressed to limit emissions.
- ESM functions, including emitter detection in the 2-18 Ghz region and coarse (3°- 5°) angle-of-arrival determination for threat warning and confirmation of attack data.
- Infrared and RF countermeasures (IRCM/RFCM) for survivability in close-in threat exposures; these may include flares and chaff, active IRCM, and towed decoys as determined by survivability analyses.
- Weapon interface, including utilities and guidance data download; the prelaunch weapon load will include GPS initialization, accurate INS transfer alignment, and target GPS (WGS-84) coordinates.

The option is reserved to add an imaging sensor as part of the SEAD UAV payload to allow both target confirmation and aimpoint adjustment, e.g., to strike an electronics van physically separated from the antenna that the emitter location system has targeted. The possibilities include a low-power synthetic aperture radar (SAR) and an imaging infrared seeker such as a forward-looking infrared (FLIR). It would be very important to exploit the limited performance required of such a sensor to hold down both cost and RCS contribution. More detailed operational effectiveness and survivability analysis is needed to validate the requirement for this sensor and to refine its characteristics.

8.3.3 Weapons

The study group established a weapon payload capacity of 800 lb, intended to be eight weapons, each weighing 100 lb. In particular, the kinetic energy penetrator was selected for the SEAD role. The kinetic energy penetrator itself has been the subject of considerable technical investigation. Existing designs developed by various contractors could be adapted to this application. The 3.5 in. diameter was selected because most of the boosted kinetic energy penetrator work conducted circa 1985 to 1992 was at this measurement and it is a proven design. This design has folding fins in the backend to provide mid-course corrections. The missile incorporates a GPS/DGPS receiver as well as an INS (to ensure target kill even if GPS is jammed). The study group proposed to adapt this design directly to the SEAD UAV system.

The kinetic energy penetrator would be capable of delivering several different warheads, including:

- High Explosive - the warhead would use a CL-20 containing high explosive capable of generating up to 450 kbar of detonation pressure to destroy the target.

- Flechette - high lethality could be achieved with 500-600 grain flechettes.

- Incendiary - the warhead would employ an incendiary explosive to generate extremely high temperature (3,700°C) persistent, high-volume reactive fireballs.

- Directed Energy - The concept would employ an explosively driven, HPM directed energy warhead capable of delivering high levels of microwave energy to destroy electronics, digital equipment, communications equipment, and other target elements susceptible to electronic upset or damage.

8.3.4 Human Systems

While automatic systems will play a role in navigation and other functions, the human will have the ability to override and directly control most functions, due to the fact that the UAV will be flying in combat and subject to battle damage. Control lags must be accounted for in relayed communications links. The operator(s) will have full access to onboard and other sensors providing a real-time-information-to-the-cockpit (RTIC) capability in the MCE. Wide angle, high-resolution cockpit views will be available on large screen color displays, providing integrated information from various EO/IR and radar sensors displayed in readily assimilated “intuitive” formats. Use of synthetic speech for warnings and voice recognition for selected control functions will be facilitated by the relatively controlled environment of the ground-based MCE.

Automated combat operation is preferred, with full fighter-type controls incorporating hands-on-throttle-and-stick (HOTAS) features provided for mission intervention. The MCE crew will include trained fighter pilots as vehicle operators. Mission rehearsal capabilities will be provided within the MCE to facilitate training and improve mission performance in the event of retasking. Rehearsal will be possible during the navigation legs. Crew station layout will be designed to facilitate the rapid decision making and response required but will be simplified by the reduction in constraints normally imposed by the need to satisfy fighter dynamics and size. The MCE will be palletized for rapid relocation.

8.4 SEAD UAV POINT DESIGN SUMMARY

The design based on the SEAD mission benefits greatly from the flexibility and small size of the payload missile. The small size permits a reasonable design which can carry eight missiles. Initially, these missiles would have combined effects bomblets, flechette, incendiary, or high explosive warheads. The use of offboard sensors and targeting helps keep both the UAV and missiles small. Thus, target kill can be achieved by employing GPS-updated inertial guidance after target radar radiation is eliminated.

In the far-term, it may be possible to develop recce-strike versions with a HPM generator on the vehicle. The weapons bays could be used for electronic gear and antennas. The vehicle could loiter, detect emitters, attack the emitter with HPMs, monitor to see if the attacks were successful, and, if not, reattack the emitter.

The point design was prepared to give a first-order sizing of a combat UAV. It shows that a relatively compact aircraft capable of multiple SEAD kills is possible. Fundamentally, the combination of stealth and unmanned operation allows an impunity that makes smaller weapons effective, thereby providing multiple kill capability. It is important that integration and modularity be key considerations in the design of such a vehicle, not only for the success of the concept but also for the flexibility to accomodate multiple payloads and missions. The SEAD UAV might be built for $5M-$10M. Along with double the number of kills per mission likely and long-term storage utilized to reduce operational and support costs, substantial life-cycle cost savings are possible.

The Air Force can use this first-order calculation as a point of departure for a detailed design of a SEAD UAV. The greatest threat to a successful program based on this point design is requirements growth: adding missions that increase size, weight, cost, etc. Hence, close control of such a program is essential.

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Chapter 9

Special Matters

A number of special issues and challenges relate to the development and operation of UAVs in the Air Force. The study group chose to deal with these separately, using individuals or team cells to address the subjects. What follows is a synopsis of these issues and our suggestions. For detail, the reader is referred to Chapter 7 in Volume II.

9.1 OPERATIONAL ANALYSES

The Air Force is faced with complex tradeoffs when deciding what and how many UAVs to buy and for what missions. The goal is to provide the Air Force with an approach that can be adapted to its needs, hopefully ensuring that important aspects of the analyses are not overlooked or suppressed unless it is explicit.

Given the complexity of this issue, time should be taken to define, in the broadest possible terms, what the Air Force wants to accomplish by adding UAVs to the force structure. Is it to save money? If so, in what areas? Is it to reduce personnel costs? Is it to complement or supplement manned aircraft in their missions? Is it to replace a manned aircraft system? Is it to do a mission or task the Air Force cannot do today? Each of these questions poses a different set of trade questions that must be carefully asked and issues carefully stated to ensure objectivity and correctness to the extent possible. Aimed premises lead to biased conclusions. The following steps are important to the analysis.

9.1.1 Defining the Missions/Tasks and Operational Concepts

An important part of problem definition is not only to define what missions/tasks to perform and how but also to take stock of what vehicle design and performance characteristics are implied by operational concepts and whether technologies are mature enough to support the design and performance goals.

9.1.2 Relating Technologies to Operational Needs

The next important step is a screening process to determine those concepts that should be included in the trade studies. The relationships between UAV tasks and requirements (high, medium or low altitude, low observables characteristics, endurance, speed, payload, etc.) must be defined. Also, sensor and other mission systems must be related to each of the operational tasks, indicating both the criticality of a given mission system to a task *and* the availability of the technology to support the need.

9.1.3 Elements of Cost

Estimating cost is often an art. This is particularly true for systems that are performing new tasks with technologies not heretofore used. Estimating costs for evolutionary systems and subsystems is not simple, but there is a process and there are analogs which help guide the cost estimator. Parametric approaches against existing manned aircraft costs must be applied with care, for an unmanned aircraft will entail a very different design approach (components, safety factors, testing, etc.).

9.1.4 Comparing UAVs With Manned Systems

To complete the comparison fully and fairly, care must be taken to define and describe in sufficient detail what the manned platforms do and why. It is not necessary that a *single* UAV replicate the manned aircraft mission performance. What matters is that UAVs perform the mission/task more cost-effectively than a manned aircraft.

9.1.5 Choosing the Scenarios for Evaluation

The Air Force is obligated to use some scenarios for force structure analysis. Scenarios that may be more likely than an MRC should also be included. It may be desirable here to use gaming as a means to both select and understand non-MRC scenarios for evaluation. Indeed, the gaming experience will enable a better choice of quantitative analysis methods.

9.1.6 Analysis Tools

Several analytic methods will be needed. At the *system* and *subsystem* level, more *detailed simulations* of performance are needed and have value in selecting and sizing systems. These simulations and analyses produce results in terms of performance at various levels.

A *mission-level* model will be preferred where small numbers of a UAV type are being considered to perform a special mission. The mission-level model will aid in comparing UAV options with one another, as well as with manned aircraft. Important outputs will include survivability per mission and over some number of missions, mission success, resources expended, etc. Outputs from this level could be input to the next level, if appropriate.

Next, a *campaign* methodology that includes resource allocations should be used to determine where UAVs are preferred over conventional options for mission/task accomplishment. The resource allocation aspect is very important. It aids the Air Force in arriving at best use of forces, hence, best return on investment. The resource allocation method is two-sided, permitting intelligent, adaptive behavior by the opponents depending on the objectives they seek to achieve. Currently, dynamic resource allocation is not part of the Air Force's analysis process.

9.1.7 Summary

The operational analysis of UAVs is important to UAV program decisions. The study group found the models for such analysis are not well developed. The Air Force should identify the appropriate activity, assure it is populated with operational, engineering, and modeling experts, and provide the funding to conduct thorough and accurate studies that consider all the factors briefly described above.

9.2 C^3I ARCHITECTURES

UAVs can be integrated successfully into Air Force air operations if their capabilities are carefully matched to mission needs and to interfaces with ongoing operations. These interfaces can be addressed, in large part, by integrating the UAV with the existing and emerging infrastructure for C^3I. Each mission creates its own needs for C^3I integration, as well as design considerations for the entire vehicle, sensors, onboard computers, and perhaps weapon components.

Important C^3I factors include the vital need to maintain positive control of UAVs, including the capability for human operators to intervene quickly to regain control of an errant, autonomously controlled vehicle. Mission planning systems are on the critical path for mission success for UAVs, and this technology must be enhanced significantly to allow UAV operation with needed C^3I connectivity. New ideas in autonomous controllers and associate systems that support and collaborate with human operators in a hierarchical command structure and new concepts for passing targeting and intelligence data from the sensors to the shooters are being addressed by Service researchers. Several C^3I architectural concepts described in Volume II may offer ways to enhance UAV military mission effectiveness.

Interoperability with existing and emerging C^3I architectures for the Air Force appears to be feasible for UAVs as long as high-level planning includes UAV capabilities and performance constraints. The principal C^3I challenge remains positive control in shared airspace with manned forces, and the key technology needed is powerful software and hardware to enable real-time, onboard mission replanning for the complex set of UAV missions that are anticipated.

9.3 SURVIVABILITY

Survivability of UAVs is a complex and critical issue. In each specific UAV design, survivability features must be balanced carefully with objectives such as mission performance, cost, and maintainability. Accordingly, in the future UAVs will be designed for very difficult threats at one end of the spectrum and relatively benign threat environments at the other end. The advantage of persistence will make survivability tougher; use of multiple UAVs in clusters will make it easier.

Like designs for manned aircraft, specific UAV designs will require the appropriate mix of signature control, tactics, emission control, and onboard and offboard countermeasures. In all cases, UAV mission planning must be accomplished in a rigorous, high-fidelity manner since threat avoidance, whenever possible, is a fundamental element of survivability for all current and future UAVs. The future UAVs described in this report will certainly require a new generation of mission planning system to rapidly generate specific “best mission cost-benefit” mission plans and flight profiles for each mission-specific set of threats.

An increasing array of signature control technology is available for future UAV designs, when required, in the area of radar cross sections, infrared signature, acoustic signature, and visual signature. These technologies include vehicle shaping, radar absorbing materials, radar absorbing structure, infrared signature reduction techniques, and low-observable sensor apertures, engine inlets, engine nozzles, and other exterior components.

Self-protection can be achieved by several methods, such as onboard passive and active electronic countermeasures, and in very unique situations—such as encounters with major pop-up threats—near-time intervention by the mission controller. In each specific UAV system design, the tradeoffs, usually based on costs of alternative systems, must be made to assure that the selected self-protection capabilities are clearly cost-effective.

To support the design and survivability analysis of a future UAV system, the Air Force and its contractor community have an increasingly more capable and mature inventory of computer codes. However, many of the codes require state-of-the-art parallel supercomputers to be used effectively. In general, then, the tools are available to do realistic survivability analysis of planned UAVs. Also, both the Air Force and several contractors have very capable test facilities to measure the RCS of UAVs at all frequencies, either using the actual UAV or, before the UAV is built, a full-scale, high-fidelity model of the UAV.

This is not to imply that developing, where required, highly survivable UAVs is easy: in fact it is a difficult task. Each specific UAV conceptual design described in Volume II includes a brief statement of the low-observable technology required to achieve a high level of survivability while performing the required mission. It was not within the scope of this study to perform a quantitative survivability analysis of any of the proposed UAVs.

9.4 INF, START, AND CFE AGREEMENTS

This study led to careful review of the arms control agreements and treaties that may pertain to the future use of UAVs. Although no arms control agreements limit UAVs directly, the Intermediate Nuclear Forces (INF) Treaty and the Strategic Arms Reduction Treaty (START) limit them indirectly or have the potential to do so, depending on system characteristics. Strict reading of the INF definition of "cruise missiles," that is, "an unmanned, self-propelled weapon delivery vehicle that sustains flight through the use of aerodynamic lift over most of its flight path," would bring attack UAVs under control. Both treaties use similar criteria to determine if a cruise missile is subject to their provisions: launch mode (air or ground), range (essentially greater than 500 km), and whether or not the missile is a weapon delivery vehicle. Except for the weapon delivery role, cruise missiles and UAVs are similar.

Continuation of the intelligence, surveillance, and reconnaissance role for the UAV appears to be in no conflict with the treaties because it would not be a weapon delivery vehicle. However, conversion of an existing UAV to a weapon delivery role might subject all UAVs of the same type to the arms control restrictions or to a possible ban altogether.

A cruise missile captured under START would be considered a long-range nuclear ALCM until the US demonstrated, during a START exhibition before the Joint Compliance and Inspection Commission, the differences that distinguished it from a long-range nuclear ALCM. Thus distinguished, it would become a long-range ALCM, and if its range exceeded 600 km, the aircraft launching it could be captured as a bomber.

Clearly, the routine operation of UAVs as now envisioned was not contemplated during the treaty negotiations. The START treaty article-by-article analysis states that the cruise missile definition distinguishes cruise missiles from air-to-surface ballistic missiles and remotely piloted airplanes. A thorough review of the negotiation record would be necessary to determine whether this type of UAV could be considered a remotely piloted airplane and thus not captured under START. As specific designs are determined for a weapon delivery vehicle type of UAV, they will require DoD Compliance Review Group analysis early in the program for a case-by-case determination of permitted or prohibited fielding under INF and/or START.

In any event, the treaty provisions should not preclude or limit UAV technology development, for there is a precedent for excluding UAVs,[11] and it is our belief that other UAVs could be excluded as well.

[11] The Tacit Rainbow radar-killing UAV was specifically excluded from the START treaty, although it was never produced.

9.5 ACQUISITION STRATEGY

In this study of UAV technologies and air combat operations, a review of the acquisition process of current systems is warranted. Certainly, the UAV presents a classic case for the Air Force to combine and integrate both technology and capability. The goal is to insert technology to improve the US capability to win wars.

Recently, the ACTD has emerged as a method of shortening the time to demonstrate a system operationally. Development of the Tier II Plus and Tier III Minus systems has followed this methodology. The SAB strongly supports the ACTD concept. As this demonstration model matures, there are opportunities to improve the transition process to field truly superior UAV systems.

During the current UAV ACTDs, the lessons learned must be collected and analyzed. An early lesson is that the designer must pay careful attention to the reliability, maintainability, and supportability aspects of the program. Since these are technology demonstrations heavily concentrated on engineering solutions, the long-term life-cycle concerns often are neglected. Another lesson learned is that an event-oriented transition plan from demonstration through production is necessary. Management decisions need to designate accountability and responsibility for the various phases of the program. Event-driven milestones with coordinated entrance and exit criteria are required.

Early in the demonstration phase, it is important to consider the threat postulated against the use of such vehicles. A parallel effort to begin drafting a System Threat Assessment Review based on intelligence estimates would be important for downstream decisions on configuration, force size, and production. Modeling and simulation of the end-to-end systems are required to achieve the confidence levels for reliability. Experience, including an accident, indicates that a disciplined flight test approach that utilizes the Air Force's extensive airplane heritage is required.

It is important to hold a single entity responsible for the total system in the development of UAVs. Government integration has led to problems in other programs in the Air Force. Although faced with difficult interface and integration challenges, the Government should resist becoming the Total System Performance Responsibility leader and leave that to the prime contractor. Strong leadership by the Government in establishing guidance, standards, and common environments is essential for successful integration of varied payloads and equipment.

It is unlikely that the desired production version of a UAV would be identical to that demonstrated in the ACTD; it would probably include lessons learned during the ACTD. The study group recommends a parallel engineering task to evolve a "preferred weapon system concept." This would be an effort to evolve a production design during the ACTD, but an entirely separate effort that would not dilute or compromise the demonstration effort. This parallel effort would complement the technical demonstration in allowing configuration, performance, payload, operational concepts, and supportability concepts to be considered and traded to achieve the most cost-effective solution.

Similarly, it is recommended that operations and support and MPT planning and programming be accomplished in parallel with the ACTD.

In summary, the SAB strongly supports shortening the technology demonstration timelines. The new national security paradigm demands that the Air Force leverage technology to be more effective with less force structure. Life-cycle considerations for supportability must be integrated into a logical transition plan from demonstration to production. Clear accountability and responsibilities must be established. A method of evolving a "preferred weapon system concept" is offered to ensure long-term military utility. The threat postulated for the period of service must be considered to provide adequate survivability for the UAV. Finally, some cost flexibility must be allowed to incorporate the final trades necessary to satisfy the Services' operational requirements.

9.6 AIRSPACE MANAGEMENT AND DECONFLICTION

The issue of airspace management and deconfliction is key to successful operation in civil and military environments. The UAVs under consideration in this study must operate in diverse airspace environments, so appropriate approaches to airspace deconfliction are essential. For the high-altitude long-endurance aircraft, it is a relatively long climb to uncontrolled airspace (FAA-controlled airspace now extends to 60,000 feet). Such climbs require long climb corridors through what may be crowded airspace. Lower altitude UAV operations, which may be characteristic of attack aircraft concepts, will involve flight through controlled airspace, even in peacetime, for training and exercise missions. In wartime, when airspace environments are extremely crowded in certain areas, additional precautions are necessary. At this time, little thinking, planning, or action to develop agreements, rules, and procedures has been accomplished.

For operation in FAA-controlled civil airspace, there has been a desire to apply the traditional rule of "see-and-be-seen" to the UAV. This was translated into the requirement for a chase aircraft, or the use of restricted/prohibited airspace, for all UAV operations. Alternatively, one-time FAA approvals have been granted based on letter requests. There is currently an activity to define Advisory Circulars[12] to outline the desired approach to UAV flight operations, pilot qualifications, etc. FAA regulations for the design and manufacture of unmanned aircraft are also being reviewed for possible revision. Military representatives are participating in the meetings, and due consideration to alternatives to chase aircraft is being proposed.

In civil airspace controlled by other nations, international agreements are needed, the alternative being ad hoc binational agreements. The study group knows of no activity to initiate international (ICAO) discussions on UAV flight operations.

In the case of military UAV operations in areas for which airspace management and deconfliction is the responsibility of the theater commander, there are procedures for airspace coordination. The Airspace Coordination Order (ACO) decrees the sole-use corridors, designates control authorities (e.g., AWACS, CRC, etc.), establishes rules, and provides procedures for the safe passage and orbits of all manned aircraft, long-range artillery, air defense weapons, and missiles. Free fire zones and flight corridors are established as a function of time-of-day, and hence a highly dynamic airspace deconfliction process is essential.

The Air Force must begin now to think through the issue of airspace deconfliction for the broad range of environments and scenarios expected in the future.

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[12] Advisory Circulars are official FAA documents that define issues and recommend solutions. They are not regulatory in nature.

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Chapter 10

A Roadmap

The study group concluded that most of the technologies are available for successful UAV development, manufacture, and deployment in the near-term. In fact, the development of three UAVs for the Air Force is well under way. Other technologies, such as advanced engines, automation technologies, and weapons must be matured. For these technology efforts, DARPA might be an effective partner because of its strong past development of UAVs and its investment in intelligent systems.

Senior leadership is interested in employing UAVs in autonomous and complementary roles. What now remains is the need for an aggressive effort to introduce UAVs to the fighting force and to integrate the capability into the Joint Service Force structure.

The effective integration of UAVs into the Air Force lies in the successful demonstration of incremental capabilities to, or by, an audience with strong vision, dedicated to the development of operational concepts that include UAVs as close complements to manned elements. Successful demonstrations, in turn, are possible only if the Air Force acquisition staff makes bold, but correct, technical decisions regarding the design and development of UAV systems. They must consider the aircraft but also pay careful attention to the other elements: mission systems, weapons, human systems, communications connectivity, mission planning/replanning, and self-protection—all in the context of a carefully structured technical and operational architecture.

The Air Force should elevate the authority responsible for the development of UAVs to a level commensurate with the potential importance of application. A major program office should be established at the Aeronautical System Center, with suitable participation by other Systems Centers and the Laboratories. Associated with the recognition aspect is the need to elevate the nomenclature of the UAV from the traditional three-letter plus number (e.g., BQM-34) associated with electronics equipment and small missiles, to a letter-number combination (G-12, K-11, M-3, etc.) as is assigned manned aircraft (e.g., F-15).[13]

Several near-term demonstrations are specifically recommended. They will serve to test technologies, develop confidence, and determine operational concepts and architectures. Most can be accomplished with existing vehicles. One new medium-altitude UAV designed for combat roles must be designed and developed. The demonstrations are:

- *Enhanced ISR missions with ESM, foliage penetration, and advanced radar sensors, coupled with automatic target cueing or screening and advanced fusion concepts*
- *ESM and jamming payloads for detection, precision location, and neutralization of radio frequency emitting threats*
- *Fixed and moving target attack using UAVs to detect and locate the targets based on image-coordinate transformation, cueing, and advanced lightweight weapons*

[13] It was subsequently learned that a Mission Design Series (MDS) designator of “Q” has been established for UAVs.

- *Communications and navigation support, based on the DARPA UAV Communications Node concept, but adding GPS augmentation pseudolites for precision guidance under GPS jamming*

- *Suppression of enemy air defenses*

The Air Force has witnessed the birth of a new generation of UAVs—one embraced by the forward thinking of Air Force leaders. Continued high-level interest and involvement is essential during the incubation period, for just one or two failures will destroy confidence and, perhaps, the future of unmanned aircraft.

The sequence of events has allowed us to make a judgment as to when the UAV will be able to begin performing key Air Force missions and tasks. The Air Force has chosen various dates and names to denote the beginning of operational capabilities such as IOC, RAA, etc. Each has its own definition and criteria. Based on the evolutionary development of technologies and the critical integration of these technologies into aircraft, time periods were defined for the beginning of operational demonstrations of mission concepts and tasks—Near-Term (1996-2005), Mid-Term (2005-2015), and Far-Term (2015-2025). The study group believes that the development and test of UAV-based capabilities will be sufficiently complete to begin operational demonstrations of the 22 mission areas as shown below in Table 10-1.

Table 10-1. *Timeframes for Initial Operational Demonstrations*

Air Force Capabilities	***Near-Term (1996 - 2005)***	***Mid-Term (2005 - 2015)***	***Far-Term (2015 - 2025)***
Sustain Nuclear and Conventional Deterrence		Strategic Attack	
		Space Control	
Project Long-Range, Sustainable, Lethal Combat Power	***FIXED TARGET ATTACK***		
	Base Defense		
	SEAD		
	THEATER/CRUISE MISSILE DEFENSE		
	MOVING TARGET ATTACK		
		Special Operations	
		Area Denial	
		Decontamination and Defoliant Dispensing	
		AIR-TO-AIR	
			CWMD
			CSAR
			Trans/Post SIOP
Support Rapid Global Mobility		Tanker	
			Cargo Transport
Provide Global Situational Awareness	***ISR***		
		Humanitarian Assistance	
Dominate the Information Spectrum	***UCN***		
	JAMMING		
		Information Warfare	
		GPS Augmentor	
Assumptions	• Complement to manned vehicles • Current Tier platforms, mission systems, & weapons • Use of UTA	• New UAV platforms • New mission systems & weapons • New UAV C^2 systems	• Autonomous or complementary • Robust C^3 • Out-of-box platforms, mission systems, & weapons

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Chapter 11

Recommendations

The study group identified cross-cutting (universal) technologies, made a first-order assessment of technologies available or needed for specific applications, and suggested a roadmap for technology development. Some recommendations for technology base programs were made. Moreover, the study group determined the need to aggressively pursue both development and demonstration programs. The following 11 recommendations summarize the actions needed now to realize the potential of UAVs.

Recommendation 1 - ***Take the lead role in programs to expand the missions of the near-term (T2, T2+, T3-) UAVs in Air Force, Joint, and National roles.*** These aircraft can serve many additional force enhancement roles, offering the economy of quantity production. Palletized payload bays can provide for roll-on, roll-off missionized approaches. Some relatively near-term possibilities for demonstration are:

- Enhanced ISR payloads, including advanced radars and multiplatform precision emitter location, including onboard processing to reduce downlink data rates and facilitate the interpretation and exploitation of collected information.
- Virtual ABCCC (ESC Initiative) - Relays all communications to rear ground location. Brings crew to a safe haven.
- UAV Communications Node (Army/DARPA Initiative) - Provides self-deploying (no need for in-theater support structure) communications support to early-entry forces. Might also provide GPS augmentation as a solution to jamming vulnerabilities.
- Target Engagement Support (direct targeting support to the shooter) - Goes beyond the current reconnaissance-surveillance roles for the Tier aircraft to a role of Joint STARS extension for real-time target selection, weapon assignment, and attack (particularly useful for time-critical targets).
- Virtual Rivet Joint with TDOA precision emitter location - Receivers operated remotely from ground sites, with collected SIGINT relayed to ground exploitation centers or targeting facilities. Brings crew to a safe haven.

Recommendation 2 - ***Pursue the SEAD mission as an early application of UAVs in an attack role.***

- Initiate design studies to define a low life-cycle cost operational SEAD vehicle using the SAB-developed point design as a starting point.
- Build a few SEAD cued attack UAVs with avionics and weapons in an ACTD structure to develop operational concepts for SEAD UAVs as adjuncts to manned aircraft.
- Conduct operational evaluations of the effectiveness and utility of the SEAD UAV system.
- The SEAD vehicle relies on a precision emitter location capability (recommended as a growth ISR UAV payload) or other precision cue.

Recommendation 3 - ***Initiate a program, perhaps with DARPA, that leads to the development and deployment of penetrating combat UAVs in the mid- to far-term.***

- Employ existing manned fighter aircraft as test beds to explore and define the requirements, technologies, and operations concepts necessary to remove the pilot from the cockpit.

- Exploit performance UAV technologies and life-cycle cost methods, as well as manned vehicle technology advances, to design a new, low-cost, operational combat UAV system.

Recommendation 4 - ***Increase emphasis on effective techniques for flight management and employment of UAVs.***

- Support research in cognitive sciences and engineering to foster effective automation.

- Initiate a program to define a systematic process for function allocation between humans and automation.

- During development, make the satisfaction of quantitative human performance requirements obligatory for human functions.

- Establish a robust process for operations and support manpower requirements determination during ACTD programs.

In order to learn quickly during the flight and operational tests of the near-term UAVs, immediately establish a program to carefully evaluate the flight operations of the Predator, Dark Star, and Global Hawk programs to assure maximum understanding of both ground crew station and air vehicle human factors and automation aspects.

Recommendation 5 - ***Establish UAV experimental capabilities to address crew-vehicle flight management concepts.*** Include:

- A multi-discipline staff (e.g., operations, human factors, cognitive sciences, systems engineering). Use the Air Force Armstrong Laboratory, universities, and industry.

- A reconfigurable crew station experimental facility for experimental investigation and rapid prototyping of UAV control station functions, displays, and controls.

- A testbed aircraft (F-16?) configured to explore the full range of control, from fully manned to fully autonomous, for combat air operations. Testing a full range of possible man-automation mixes will aid in optimizing UAV control.

Recommendation 6 - ***Expand work in critical enabling platform and propulsion technologies.*** Work should include:

- High-altitude, fuel efficient engines

- Structural design methods for high reliability for a limited life

- Lightweight, low-cost composite structures manufacturing

- Mission flight executives for vehicle/flight control

- Engine and structure ATDs

- Integrated design approaches for UAVs

Recommendation 7 - ***Supplement avionics and mission systems technology base programs in areas critical to UAV operations.*** Though most of the mission systems technology appropriate to UAVs is relatively mature, some additional efforts and demonstrations are very important:

- Develop techniques and algorithms for higher orders of mission system autonomy.
- Place major emphasis on automatic target recognition (ATR) programs.
- Support subsystem and component miniaturization in high-payoff areas.
- Explore alternatives for low-cost, low-observable sensor apertures and windows.
- Investigate use of unattended ground sensors (UGS) in conjunction with manned and unmanned aircraft. UAVs provide ideal control and communications relay platforms for UGS use.

Recommendation 8 - ***Initiate a modular weapons and warhead program specifically oriented to the mission tasks most suited to UAVs.***

- Create a family of UAV weapons.
  - ⇒ Transition LOCAAS to EMD/Production (100 lb)
  - ⇒ Demonstrate kinetic energy penetrator with various warheads (75-100 lb)
  - ⇒ Perform concept definition of a hypervelocity missile for BPI and air-to-air
  - ⇒ Short- and medium-range air-to-air missiles
- Develop technologies for low-cost, lightweight, highly effective warheads.
  - ⇒ Establish cooperative warhead programs with NSWC (Indianhead)
  - ⇒ Demonstrate explosively driven HPM warhead
- Develop concepts to enhance resistance to GPS jamming.

Recommendation 9 - ***Initiate a broad program to address opportunities for dramatically reducing operations and support costs for UAVs.***

- Develop long-term storage (dormant reliability) techniques suitable for UAVs.
- Formulate design methods for highly reliable, short-life UAV systems and subsystems.
- Emphasize modular, palletized construction for subsystems commonality, wide application, and mission flexibility.
- Develop maintenance concepts for the unique nature of UAVs.
- In conjunction with the above, investigate traditional and nontraditional basing concepts, unit sizes, deployments, and organizations.
- Develop a comprehensive strategy to exploit the potential for dramatic life-cycle cost savings.

<u>Recommendation 10</u> - ***Promote C^3I architectures, compatible with the TBMCS, that consider UAVs in the context of the overall Joint Forces structure.*** Include:

- Mission planning
- Dissemination, data fusion
- Mission payload control
- Complementary activities with other weapons systems
- Airspace deconfliction
- Communications management

<u>Recommendation 11</u> - ***Develop systems, concepts, and processes for UAV airspace management and deconfliction.*** Include:

- Airspace scenario and mission planning for UAVs.
- Dynamic mission replanning for UAVs similar and complementary to that used by manned aircraft, to assure optimal mission profiles against time-sensitive targets and threats.
- Integration into the FAA and theater air traffic control environment.
- Collision avoidance equipment and schemes (TCAS, IFF, etc.).
- Consideration of multinational operation in the international airspace environment.

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Chapter 12

Concluding Remarks

A great deal of progress has been made in the technologies that would support combat and combat support roles for UAVs. Many of the requisite technologies are mature; others need additional development. Moreover, there appears to be greater acceptance of UAVs in the conduct of Air Force mission tasks. The study group concludes that a number of key missions should be pursued as development and demonstration programs by the Air Force. These suggested programs will serve to establish the utility of the UAV and develop the operational concepts.

The study group observes the need for an evolutionary approach to introducing the UAV into the Air Force mission, with special consideration given to UAV operation as complementary to manned aircraft. Such approaches to demonstrating incrementally increasing capabilities will allow technical obstacles to be overcome as well as rules and concepts to be developed for successful integration of UAVs into the civil and military airspace environment and operational tactics. An acquisition strategy with carefully selected milestones, reviews, and decision points will aid in assuring sound program management practices.

With careful management and appropriate diligence, the UAV can become an important element of the United States Air Force. The study group encourages Air Force leadership to make available the support and resources to realize the benefits of these emerging weapon systems.

UAVs have significant potential to enhance the ability of the Air Force to project combat power in the air war.

Be cautious to avoid requirements growth!

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APPENDICES

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Appendix A

Terms of Reference

UAV TECHNOLOGIES AND COMBAT OPERATIONS

SUMMARY

The Chief of Staff, recognizing the importance of unmanned aerial vehicles (UAVs) to Air Force combat operations, requested the Scientific Advisory Board to investigate advancing electronic and mechanical technologies that might enable Air Force mission roles for UAVs as well as establish the related technology areas in which further advancements are needed.

BACKGROUND

The development, test, and use of unmanned aircraft has spanned many years with little success in integrating UAVs into the combat force. Cost and reliability have been among the chief impediments to effective use. Several developments have now made UAV operations practical: high-reliability components and subsystems, differential GPS for precision waypoint and auto-land flight, lower cost sensor suites, composite structures and skins, high-efficiency engines, etc.

The recent introduction of UAVs into combat operations (e.g., Desert Storm and Bosnia) has demonstrated the value of augmenting manned aircraft with UAVs in high threat areas and for long-endurance flights associated with reconnaissance and surveillance missions. A broader range of missions including attack, special operations, combat search and rescue, and communications must now be considered.

The rapid advancement of high-reliability, low-cost electrical and mechanical components suitable for UAVs has opened a new era, just as reduced cost of air operations has become a more critical need. This study is necessary to review the Air Force position relative to the technical capabilities and technology needs of UAVs and combat operations.

TASKS

The study effort will:

- Review the state-of-the-art in UAV development in the Air Force, other Services, and other Government agencies.
- Assess Air Force roles and missions for which current technologies might enable use of UAVs to accomplish combat tasks at reduced cost or lower risk of human capture or loss of life.
- Identify the new technologies significant to the development of combat UAVs capable of conducting traditional or future and nontraditional Air Force missions.

- Make recommendations for development of those technologies unique to the UAV or for which substantial risk relative to UAV applications is present, so that future UAV missions can be made possible.

- Provide recommendations for the development of UAVs and the associated technologies.

PANELS

The study effort will consist of five panels:

- Platform Panel (Airframe, Propulsion, and Flight Control Systems)

- Mission Systems Panel (Sensors, Processing, and Communications)

- Weapons Panel (Lethal and Non-Lethal Weapons and Attack Systems)

- Human Systems Panel (Ground/Airborne UAV Control, Man-Machine Interfaces, and Training)

- Operations Panel (BM/C4I, Force Integration, Roles and Missions, and New Mission Concepts)

PRODUCT

The products of the study will be a final report and a briefing.

Appendix B

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Study Chairman

Maj Gen Thomas Swalm, USAF (Ret)
Deputy Study Chairman

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Appendix C

Abstracts of Panel Reports

OPERATIONS PANEL REPORT ABSTRACT

The task of the Operations Panel was to use the range of future Air Force operations to generate a description of the contribution provided by UAVs. Future operations were divided into three groups, representing near-term (1996 to 2005), mid-term (2005 to 2015), and far-term (2015 to 2025). The first step was to generate a list of potential UAV operations. This incorporated 22 different operational mission concepts and tasks, covering a wide range, including attack of fixed and moving targets, cargo transport, humanitarian, and others. All of the operations, including those beyond the 9 published in Volume I are described in Volume II.

In most of the operational concepts, UAVs have applications in the near-term for performing mission-specific ISR. Non-ISR functions begin to be available in most cases in the mid-term (initial operational demonstrations could occur in the near-term). Possible near-term initial operational demonstrations of non-ISR functions include fixed target attack, moving target attack, communications-navigation support, TMD, SEAD, airborne communications node, jamming, and air-to-air. The technological requirements for concepts are discussed for each operation.

It is recommended that development of UAV-based operational concepts be evolutionary, ensuring reliable operational utility before incorporation into the Air Force structure. A phased approach should be utilized to demonstrate UAV flight characteristics and weapon integration before the more complex concepts and missions are started.

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PLATFORM PANEL REPORT ABSTRACT

The objective of the Platform Panel was to identify and specify the air vehicle system and subsystem technology investments most essential or beneficial to the future development of UAVs. To achieve its purpose, the Platform Panel carried out several interrelated activities, some of which are described as follows.

First, the opinions and ideas of insightful experts from inside and outside the UAV community were gathered during a series of field trips and meetings. Second, the most compelling UAV mission tasks and the minimum number of candidate air vehicle concepts needed to accomplish these tasks were identified, starting from the national military needs. Third, vehicle point designs were generated so that sensitivities to proposed technology advances could be determined. Fourth, conclusions were summarized in the form of roadmaps for critical enabling technologies and for UAV systems development and deployment. Throughout, the work was closely coordinated with the Operations, Human Systems, Mission Systems, and Weapons Panels to ensure that the study results were integrated to maximize the chances of success for UAVs.

The report concludes with a short but comprehensive list of final recommendations that includes precise descriptions of the next steps to be performed in order to capitalize on the great promise of UAVs to perform vital missions of the Air Force.

Panel Membership

Dr. William Heiser, Chair
Mr. Richard Alldredge
Dr. Richard Bradley, Jr.
Mr. Ramon Chase
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Maj Alice Chen, Technical Editor

MISSION SYSTEMS PANEL REPORT ABSTRACT

The Mission Systems Panel evaluated the electronics required onboard UAVs to perform the operational tasks that are the basics of this study and assessed the availability of technologies to implement the selected system concepts. The Panel charter covers sensors of all types—communications, navigation and geolocation, electronic warfare, fire control, and information processing. The report deals first with the mission systems of each operational task and then with summaries of the key technology areas.

In general, the Panel found that enabling technologies for basic UAV operational concepts are available or in advanced stages of development. Thus, UAV systems that add significant operational capability can be demonstrated and fielded in the near-term. For the mid- and far-terms, specific high-leverage technologies that will make feasible UAVs with greatly enhanced performance and availability have been identified and recommended for focused technology development efforts. In particular, the technologies forming the mathematical and computing basis for higher levels of autonomous payload operation, including automated evaluation of sensor inputs, have great potential.

The Panel developed the avionics content of a point design for a UAV SEAD platform, which is a major outcome of the study as a whole. The Panel's recommendations highlight the importance of an improved BM/C^4I architecture to allow UAVs to be used with maximum effectiveness. Other recommendations include near-term demonstration of UAV platforms to deal with shortfalls in communications and navigation in the battlespace, with urgent operational needs to replace manned jamming platforms and with high-precision target location to support weapons such as JDAM and JSOW. Technology recommendations deal with critical components and with technologies that enhance affordability.

Panel Membership

Dr. John Borky, Chair
Mr. Geoff Butler, UK Defence Research Agency
Dr. Curtis Carlson
Mr. Lynnwood Cosby
Dr. George Davis
Prof. Daniel Hastings
Dr. Stephen Iglehart
Dr. Charles Morefield
Dr. F. Robert Naka
Dr. Stanley Robinson
Dr. Gunter Stein
Prof. Duane Stevens
Dr. Michael Yarymovych
Maj Thomas Pauly, Executive Officer
Capt Brian Mork, Technical Editor

WEAPONS PANEL REPORT ABSTRACT

UAVs are under consideration for a number of Air Force missions and tasks. Some will require weapons to effectively kill difficult targets. Long endurance and other unique attributes of the UAV enable it to deliver weapons more effectively in some of these tasks. These include CW/BW neutralization, SEAD, boost phase intercept of tactical ballistic missiles, and interdiction of some hard targets.

Analysis of elements of these tasks, evaluation of the threat, examination of parametric design data, and review of available technology led to the selection of a family of three small weapons capable of employing a family of new modular warheads. One of the weapons is on the shelf. The others employ some existing subsystems. The family of weapons/warheads provides UAVs with near-term capability to very effectively conduct the spectrum of mission/tasks identified above, as well as some collateral air-to-air missions. In addition, the weapons are candidate for delivery by manned aircraft.

The technology necessary to develop these weapons is basically in hand. To facilitate their development, it is recommended that advanced flying plate and incendiary warhead technology—the enabler of high lethality in a very small volume—be quantified (hydrocode analysis and tests) beyond the demonstrations that have already taken place.

<u>Panel Membership</u>

Mr. Theodore Wong, Chair
Mr. Milton Finger
Dr. O'Dean Judd
Maj Gen Donald Lamberson, USAF (Ret)
Prof. Digby D. Macdonald
Dr. Joseph Mayersak
Mr. Robert Millett
Mr. Gregory Shelton
Mr. Darryl Spreen
Maj John Foley II, Executive Officer
Capt Thomas Bailey, Technical Editor

HUMAN SYSTEMS PANEL REPORT ABSTRACT

The task of the Human Systems Panel was to identify significant human-system issues in the development and deployment of UAVs for various missions identified by the Operations Panel and to recommend technical requirements, research needs, or process changes necessary to assure effective integration of the human. The role of the human, human systems interface technology, command and control, and maintenance and personnel training issues are addressed.

Determining the degree of autonomy and functions of the human is a vital front end concern that drives design. Simulations of various types, including man-in-the-loop "gaming" simulation, are effective methods of supporting function allocation and these simulations should be performed early in concept development. Research in how to promote situation awareness is required. Designing methods to keep the human in the loop will be a challenge to display format designers if the system is relatively autonomous.

The ACTD process has largely ignored manpower, personnel, and training requirements and a systematic and timely method of addressing these needs must be implemented.

Panel Membership

Dr. Richard Gabriel, Chair
Mr. Jeff Erickson
Mr. Dave Hoagland
Mr. Doug Hosmer
Dr. John Howe, III
Dr. John Retelle, Jr.
Dr. Henry Taylor
Mr. Richard Weeks, UK Defence Research Agency
Dr. Harry Wolbers
Ms. Roxanne Constable, Executive Officer
Capt Sandra Eisenhut, Technical Editor

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Appendix D

Distribution List

Headquarters Air Force		
SAF/OS	1	Secretary of the Air Force
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AF/CVA	1	Assistant Vice Chief of Staff
AF/ST	1	Chief Scientist
AF/TE	1	Test and Evaluation
AF/LRP	1	Long Range Planning
AF/HO	1	Historian
Assistant Secretary for Acquisition		
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AQX	1	Management Policy and Program Integration
AQL	1	Special Programs
AQI	1	Information Dominance
AQP	1	Global Power
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XOO	2	Operations
XOR	2	Operational Requirements
XOF	2	Forces
XOX	2	Plans
XOM	2	Modeling, Simulation, and Analysis

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Deputy Chief of Staff, Command, Control, Communications, Computers		
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SCM	1	C4 Mission Systems
SCT	1	C4 Architectures, Technology and Interoperability
SCX	1	Plans, Policy and Resources
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AF/PE	1	
AFPEO/AT	1	Airlift and Trainers
AFPEO/SP	1	Space Programs
AFPEO/FB	1	Fighter and Bomber Programs
AFPEO/C3	2	C3 Programs
AFPEO/BA	2	Battle Management
AFPEO/WP	2	Weapons
AFPEO/JL	2	Joint Logistics Systems
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OUSD (A)	1	Under Secretary for Acquisition
USD (A)/DSB	1	Defense Science Board
DDR&E	3	Director, Defense Research & Engineering
ASD/C3I	1	Assistant Secretary of Defense for C3I
OUSD (AT)	1	Deputy Under Secretary for Advanced Technology
BMDO	1	Ballistic Missile Defense Organization
DARO	5	Defense Airborne Reconnaisance Office
DARPA	5	Defense Advanced Research Projects Agency
Other Air Force		
AFMC ST WL, AL, PL, RL, OSR ESC, ASC, HSC, SMC	1 2 5 ea. 1	Air Force Materiel Command Command Section Science and Technology Labs and AFOSR Product Centers
ACC	3	Air Combat Command
AMC	1	Air Mobility Command
AFSPC	1	Air Force Space Command
PACAF	3	Pacific Air Forces

USAFE	3	US Air Forces Europe
AFOTEC	1	Test and Evaluation Center
AFSOC	1	Air Force Special Operations Command
AIA	2	Air Intelligence Agency
NAIC	1	National Air Intelligence Center
USAFA	1	Air Force Academy
AU	1	Air University
AFIWC	1	Information Warfare Center
AFIT	1	Air Force Institute of Technology
NGB/CF	1	National Guard Bureau
AFSAA	5	Air Force Studies and Analysis Agency
Army		
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ASB	3	Army Science Board
Navy		
ASN (RD&A)	1	Assistant Secretary of the Navy for Research, Development and Acquisition
NRAC	1	Naval Research Advisory Committee
NAWC	3	Naval Air Warfare Center
NRL	3	Naval Research Laboratory
ONR	2	Office of Naval Research
Joint Staff		
JCS	1	Office of the Vice Chairman
J2	1	Intelligence
J3	1	Operations
J5	1	Strategic Plans and Policies
J6	1	C3 Systems
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Study Participants	1 ea.	
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ANSER	2	
MITRE	2	
MIT Lincoln Lab	2	
RAND	2	
Air Force Science and Technology Board	1	
Naval Studies Board	1	